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VACUUM JACKETED UMBILICAL LINES
TECHNOLOGY ADVANCEMENT STUDY

VACUUM PROBES

AMETEK/Straza
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El Cajon, California 92021

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January 5, 1970

Final Technical Report, Task V
Contract Number NAS 10-6098

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
John F. Kennedy Space Center
Design Engineering - Mechanical Systems Division
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AMETEK/Straza

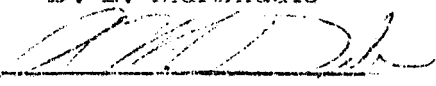
Final Report
for
Vacuum Jacketed Umbilical Lines
Technology Advancement Study
Task V
Vacuum Probes

Contract Number NAS 10-6098

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16. Abstract This document presents the results of the Evaluation Study for Vacuum Probes. Areas of study covered in Phase I were hardware evaluation at the Kennedy Space Center, product review of presently available vacuum probes, a state-of-the-art investigation, and a design phase. The design phase was followed by a Phase II proposal. Phase II consisted of a test program which basically included environmental testing of vacuum probes already in production by several manufacturers. The test specimens underwent all environments found at Cape Kennedy during standby and launch conditions. Results of the hardware evaluation of the thermocouple vacuum probes at Launch Complexes 34 and 39 at the Kennedy Space Center showed a reliability of 0.8400. Failure was due mostly to vibration, shock, and corrosion. The study and test results indicate that attainment of reliability of 0.91 is within present state-of-the-art and 0.96 is likely. Several types of vacuum measuring devices were investigated and the conclusion was that the thermocouple device was the most practical for the launch complex environment. Upgrading of resistance to shock, vibration, and corrosion was found necessary.					
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ABSTRACT

This document presents the results of the Evaluation Study for Vacuum Probes. Areas of study covered in Phase I were hardware evaluation at the Kennedy Space Center, product review of presently available vacuum probes, a state-of-the-art investigation and a design phase. The design phase was followed by a Phase II proposal. The Phase II study contains the test report which sets forth the results with data of the environmental and functional tests performed in evaluating the selected vacuum probes. These specimens were procured from Cryolab, Fredericks, and Hastings-Raydist. The test specimens underwent all environments found at Cape Kennedy during standby and launch conditions.

Results of the hardware evaluation of the thermocouple vacuum probes at Launch Complex's 34 and 39 at the Kennedy Space Center showed a reliability of 0.8400. Failure was due mostly to vibration, shock, and corrosion. Several manufacturers of vacuum probes (thermocouple type) are aware of these problems and have designed and manufactured probes for specific use at the Space Center with consequent up-grading of the reliability which is, with state-of-the-art consideration, 0.91. Several companies produce vacuum probes which will likely attain a reliability of 0.964.

A number of different vacuum probes were considered, such as heat conductivity capacitance, mechanical manometers, etc. (see Paragraph 5.2.1). As the study progressed it became apparent for reasons of operating requirements and cost that the thermocouple type vacuum probe was adequate for its intended application at the Space Center if the unit was designed for increased resistance to shock, vibration, and corrosion. Several companies meet these criteria; Hastings-Raydist, Cryolab, and Fredericks.

Design parameters for a thermocouple probe for use at the Kennedy Space Center include a stainless steel body of Type 316 Corrosion Resistant Steel, corrosive resistant contact pins, a protective cover for the contacts, miniaturization to reduce the effect of vibrations and shock and keeping the heater and/or thermocouple wires slack to minimize vibration effects. Design consideration is also made of installation and re-calibration methods to lessen chances of human error and to improve the confidence level of the user.

Phase II consisted of a test program which basically included environmental testing of vacuum probes already in production by several manufacturers. A procurement specification has been written incorporating design aspects required to enhance performance.

CONCLUSIONS

During the study phase of the vacuum probes, it was determined that a thermocouple type vacuum probe was adequate for use at Cape Kennedy, particularly if the reliability was maintained at a high level. Reliability has been increased by miniaturization of the vacuum probe envelope to increase its mechanical resistance to shock and vibration. Electrical resistance to vibration and shock can be obtained by using sensing wires of 1 mil or less. Protective covers are employed to protect the electrical connector's gold-plated pins from the environments of salt fog and sand and dust. Test results show that the low envelope profile and fine sensing wires improve the vacuum probe's resistance to shock and vibration. The Hastings-Raydist vacuum probe failure during vibration is attributed to the thermopile beads located at the thermocouple junction. The protective covers provide protection against external environmental contamination. However, the vacuum probes with finer sensing wires appear to be more sensitive to internal contamination. Both the Hastings-Raydist and Cryolab probes with wires of 1 mil or less showed greater variation in readings than the Fredericks probe with 4 mil diameter sensing elements.

No problems were encountered during testing with installation procedures. During testing, out of specification readings were noted for various vacuum probes. However, with an allowable level of 1000 microns, none of these readings would be cause for vacuum jacketed line rejection. The vacuum probe should be considered an indication of vacuum level and not an accurate measuring device in this application.

In summary, it was determined that the thermocouple type vacuum probe is an adequate device for installation on umbilical swing vacuum jacketed propellant lines.

RECOMMENDATIONS

As a result of the Phase II Test Program it is recommended that additional tests be conducted to determine the drift rate of thermocouple type vacuum probes at known vacuum levels over extended periods of time. The reason for this recommendation is that variations in readings were noted for the same probe at the same pressure level during testing. Part of this variation was possible due to the frequent release of vacuum to atmosphere during testing. A low drift rate is desirable to enhance the ability to detect small leaks in the vacuum jacket over a short period of time.

The Fredericks Company presently supplies the vacuum probes for the vacuum jacketed lines on the Saturn Launch Tower swing arms. A second source for procurement purposes should be developed.

It is also recommended that enough gettering material be included in the annulus to allow a maximum pressure rise to 4000 micron with a repump level set at 1000 microns. This level is based on company test data showing that a vacuum jacketed cryogenic line will cryopump down to below 0.1 micron from this level when sufficient gettering material is contained within the annulus. If such a level is accepted, readout meters with an expanded scale up to 5000 microns would be required.

5.0 FINAL REPORT

5.1 PHASE I TECHNICAL REPORT

5.1.1 Hardware Evaluation

5.1.1.1 Functional Review

The propellant swing arm lines on the launch umbilical tower at Complex 39, Saturn V, are vacuum jacketed to prevent excessive loss of propellant or excessive temperature rise of the cryogenic propellants during the fuel loading operation. For a propellant line segment to operate efficiently the pressure in the vacuum jacket (annular space) should be a 0.1 micron or lower after the initial cryopumping at the start of the propellant loading operation. To achieve this vacuum level in a reasonable length of time after start of fill, the standby vacuum level in the annular space should be maintained at as low a level as practical. Presently the maximum allowable standby pressure in the annular space of the swing arm lines is 100 microns.

A vacuum sensor is installed on each line segment to indicate if the standby annular space pressure is acceptable for a propellant loading operation. At Complex 39, the vacuum sensor employed is of the thermocouple type (see Figure on Page 2).

The thermocouple vacuum probe consists of a heater wire and a thermocouple enclosed in a metal envelope with a threaded tube for mounting purposes and an electrical connector for supplying a constant current to the heater wire and to readout the millivolt output of the thermocouple. The thermocouples mode of operation is based on the principle that the heat lost by conduction from a heated resistant wire depends on the pressure of the gas surrounding the filament. A readout meter, usually battery powered is used to determine the vacuum level.

The units are exposed to the corrosive atmosphere found at Cape Kennedy and to the high shock and vibration levels during launch. Propellant line location on the swing arms (see Figures on Pages 3 through 6) makes it difficult to connect the meter to the sensor probe, increases chances of accidental damage to the probe, and makes replacement difficult when necessary. When replacement is required the vacuum integrity of the line is lost necessitating a complete repumping of the annular space. Along this same line, the probes cannot be re-calibrated once installed. The propellant lines are monitored periodically with increasing frequency prior to launch operations. Any line segment with an annular space pressure above 100 microns must be repumped, a sometimes difficult and time consuming operation.



Figure 1. Typical Thermocouple-Type Vacuum Gauges.
Note the Variation in Size and Shape.

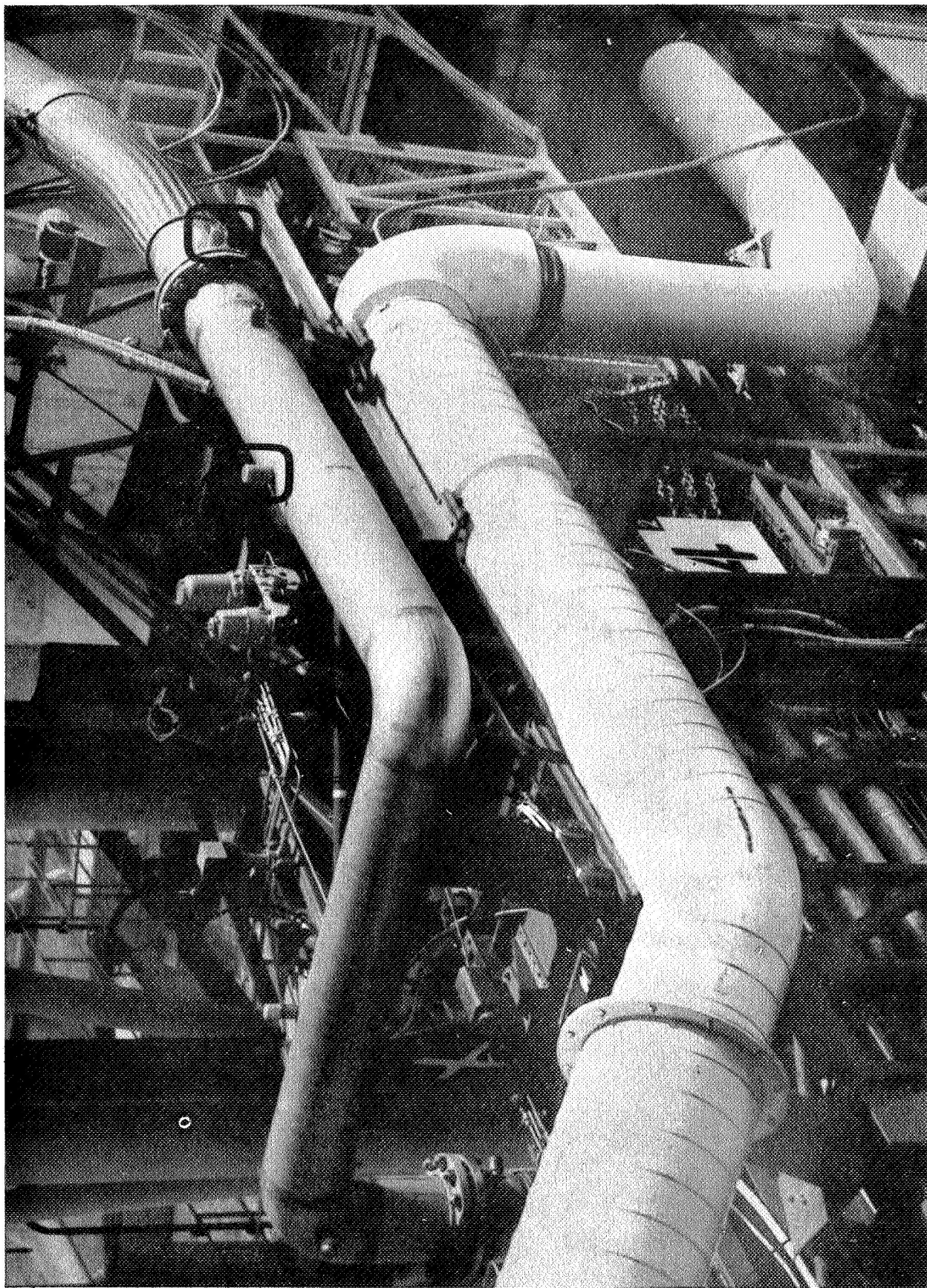


Figure 2. A Typical Vacuum Probe Installation at Complex 39. Note Saturn V in the Background.

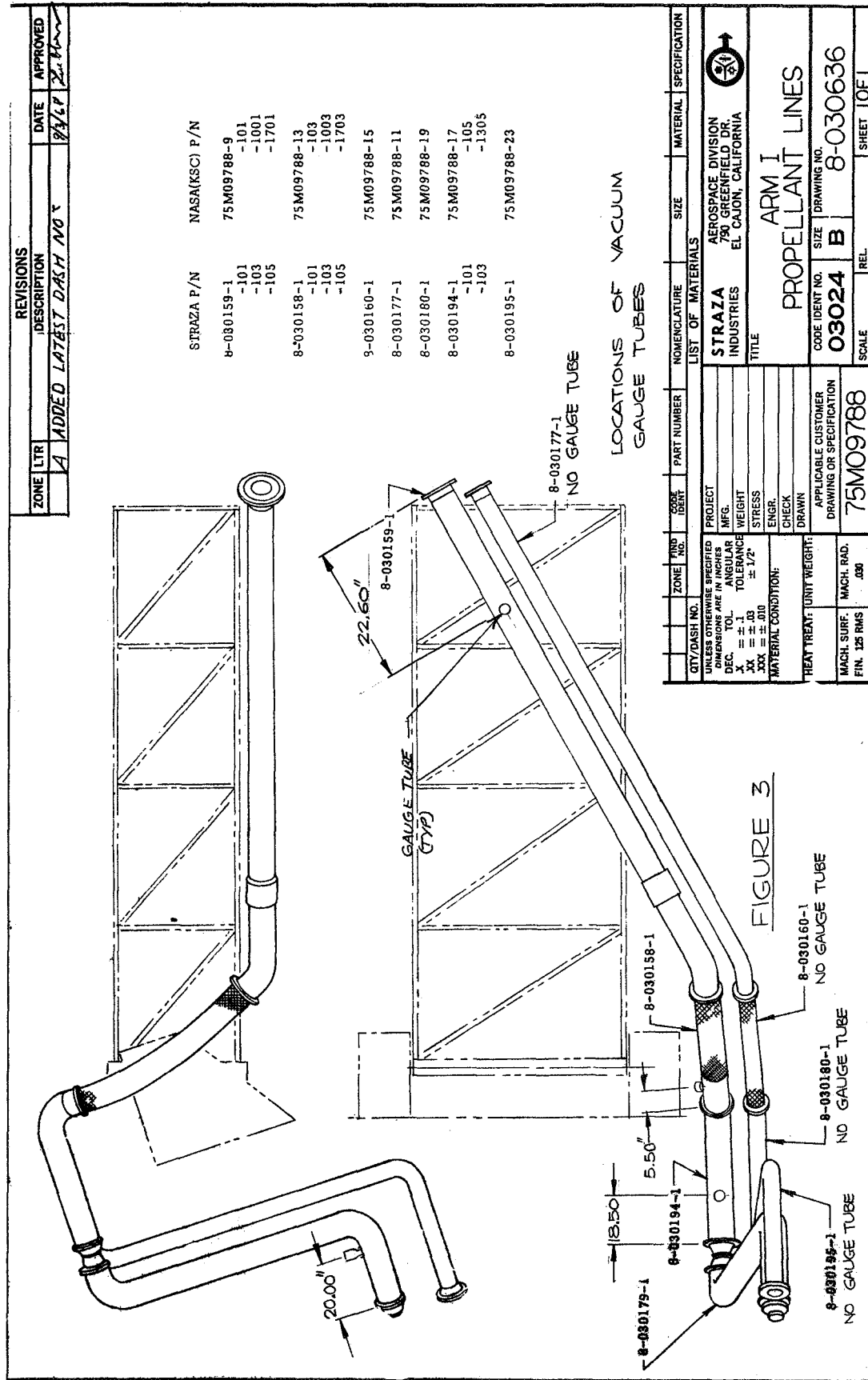
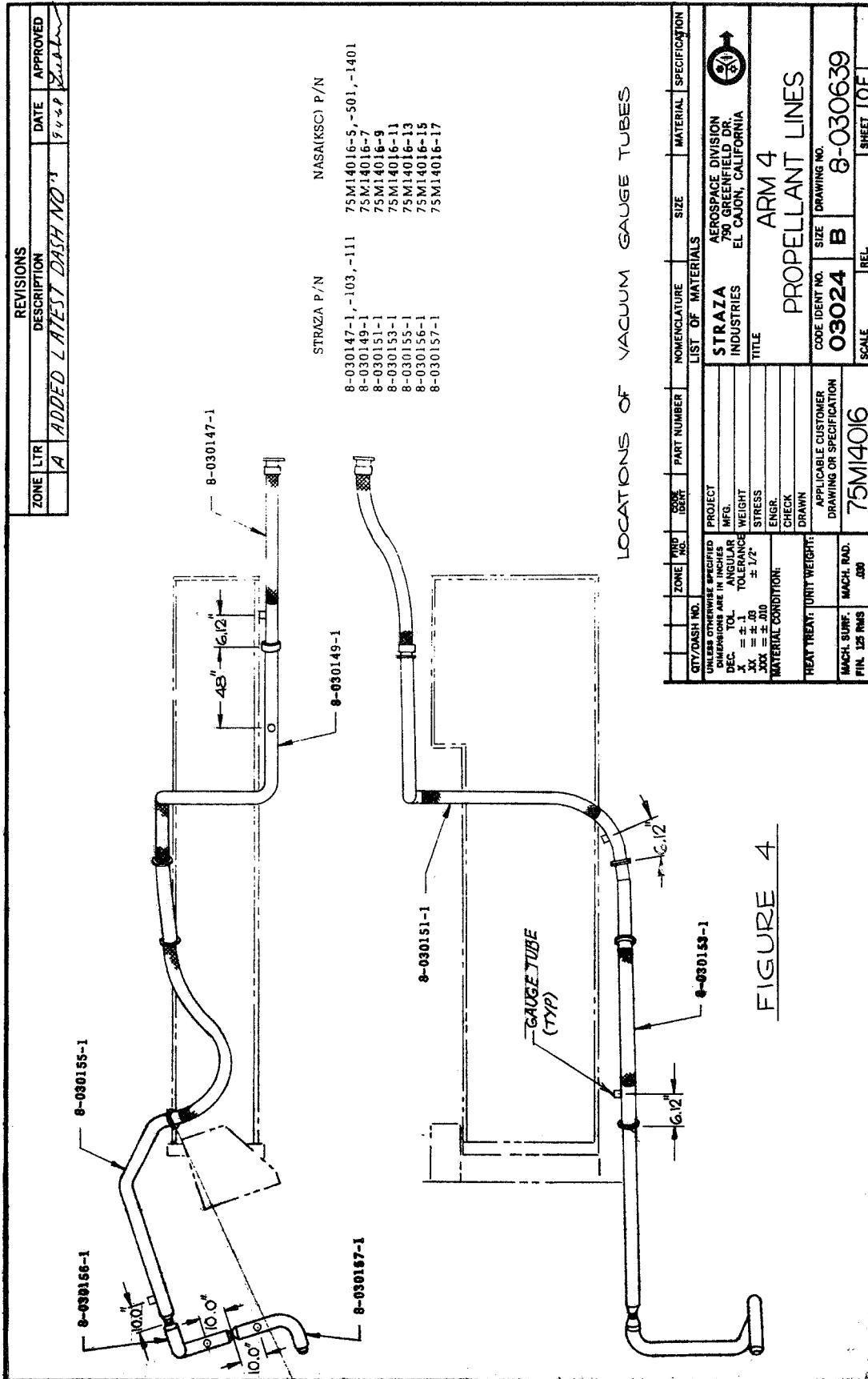


Figure 3.
AMETEK/Straza Drawing No. 8-030636, Arm 1 Propellant Lines



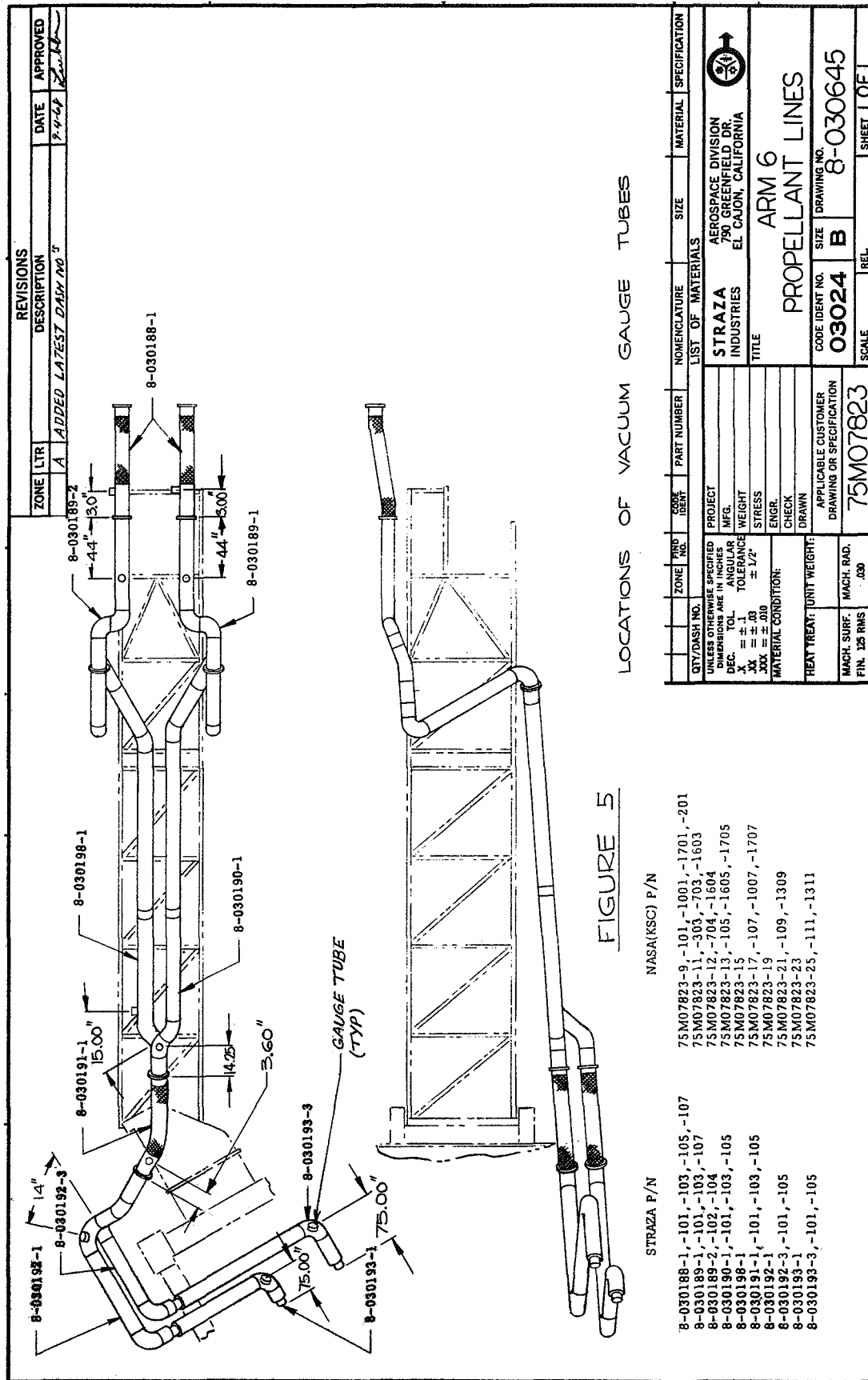


Figure 5.
 AMETEK/Straza Drawing No. 8-030645, Arm 6 Propellant Lines

5.1.1.2

Component Operating Requirements

The vacuum sensor employed at Complex 39 should operate reliably from 1 to 1000 microns to meet the requirements of acceptable standby levels. It should be mechanically and electrically resistant to vibration and shock during launch operations. Effects of corrosion should be minimized by using corrosive resistance materials for construction and by using protective covers over electrical contacts. The electrical contacts should be gold plated to reduce the effects of weathering.

The unit should last a minimum of five years with little depreciation of the accuracy over this period. Active use of the sensor is minimal when compared to its inactive standby time. Pressure level is determined once a month and more frequently during a repumping operation of the annular space.

The probe should be considered a vacuum level indicator and not a precision instrument for measuring low pressure. There are several reasons for this.

1. Thermocouple probes are sensitive to gas composition and are normally calibrated at the manufacturer with air or nitrogen. Once installed in a sealed line the gas composition is no longer known as pressure increase (with the exception of a leak) is due to outgassing of metal surfaces and insulating materials contained in the annular space.
2. The output of a thermocouple probe is nonlinear particularly above 1000 microns and below 10 microns. Very small variations in heater current can result in large excursions of apparent pressure.
3. Because the metal lines are exposed to solar radiation during the day, readings can vary as much as 25% from morning to night. This is due to the heating of the residual gasses contained in the annular space.
4. Slight resistive changes in the heater wire and contamination over a period of time will cause some variations in pressure reading.

Since, during normal operations, a line is monitored only to ensure that a predetermined pressure level has not been reached, a more accurate device is not really needed. Under the more special case of suspected leakage, the thermocouple probe is still suitable if adjustments are made for temperature effects. These changes in electrical characteristics normally occur slowly and would not affect a short term check for suspected leakage.

In addition, there should be some means provided for easy replacement of the vacuum probes without losing the vacuum integrity of the line and a means of periodic calibration.

The thermocouple vacuum probe presently in use on the swing arm propellant lines, Complex 39, Kennedy Space Center, is manufactured by Fredericks Company located at Huntingdon Valley, Pennsylvania (see Figure on Page 9). This unit has been fabricated of 304 series stainless steel with a gold-plated connector to reduce the effects of corrosion. The unit has been miniaturized to improve its resistance to vibration and shock. No known failures have occurred with this unit. However, no data is available on long term accuracy of the particular probe due to its relatively recent development.

5.1.1.3 Evaluation of Equipment

Location of the propellant lines on the swing arms and consequently the location of the vacuum probes make them difficult to connect for readout and/or replacement. The major cause of mechanical damage as reported by UCR's (Unsatisfactory Condition Reports) obtained from the Space Center is bent or broken contact pins or breakage of the center guide post. From the UCR's and company data on returned lines, mechanical damage due to bent pins or broken center posts amounts to 9% of the total failures reported. The Fredericks ruggedized vacuum probe has miniaturized pins with a guided metal connector which eliminates this type of damage.

There appears to be no great difficulty in replacement as far as actual damage to the vacuum probe is concerned; however, replacement is difficult due to the physical location of the probes (see Figures on Pages 4, 5, and 6). Because there are no provisions on the arm lines to valve off the vacuum probe from the annular space, any replacement requires that the entire vacuum annulus be repumped. This task requires a vacuum diffusion pump, along with other associated hardware such as connecting lines, a leak detector to ensure proper probe installation, and back fill gas. From the available UCR's this task takes anywhere from three to eight hours, not counting the actual down time (normally several days). There is some question as to whether the full time requirements are reflected in the UCR's.

No data was available on leakage of the probe around the threads of the stem after installation. This condition would be corrected as is, in the field with no failure report issued. Company experience shows, however, that this condition does occur occasionally.

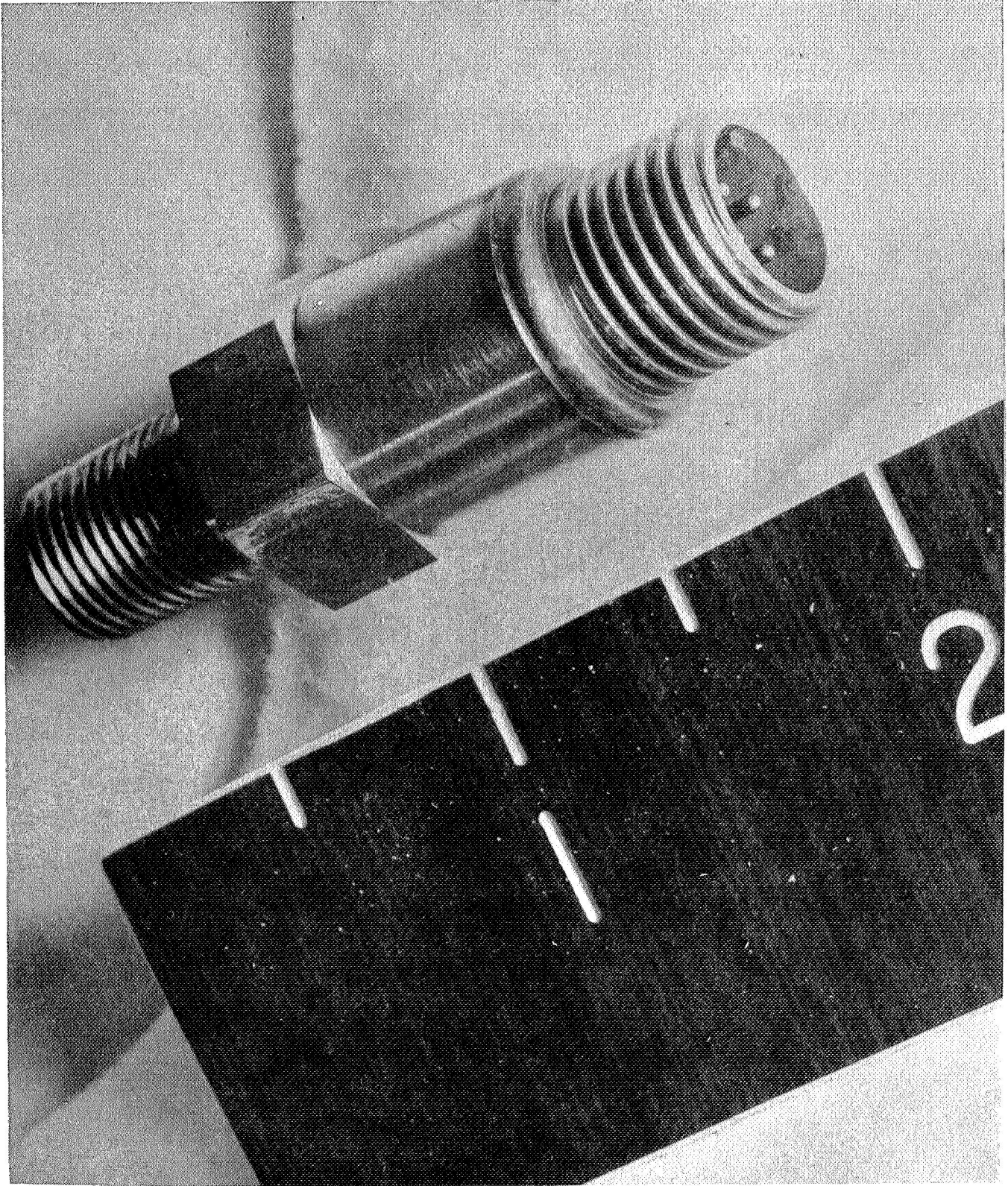


Figure 6. Federicks Vacuum Probe Model No. 2167 Installed on the Swing Arm Lines at Complex 39, Cape Kennedy.

In summary, while damage is minimal during installation and removal of vacuum probes, propellant line location on the swing arm makes it difficult to accomplish the task, particularly the necessity of repumping of the propellant lines under conditions of limited space and hazardous location of the probes.

5.1.1.4 Review of Conditions and Failures

During the data search at Kennedy Space Center, 74 Unsatisfactory Condition Reports covering the period from May 1966 to September 1968 were retrieved from the data bank delineating 264 failures and consequent replacements of vacuum probes at the Space Center. One hundred and fifty of the vacuum probes were rejected during receiving inspection because of failure to meet the specified accuracy at 450 microns. These failures were discarded as not being relevant to this study. Table I is a tabulation of report failures. It should be noted that occasionally two conditions are given for cause of failure; in particular, corrosion and electrical. No failure analysis was performed on the electrical failures so it is not possible in most cases to relate what contributed to these failures.

Of the 114 remaining failures, 76 were electrical, 27 were due to corrosion, 3 were due to broken pins, 1 was rejected for a manufacturing defect, and 5 failures were due to unknown causes. The figure on Page 15 is a typical representation of the effect of corrosion on a vacuum probe. Three types of vacuum probes were represented in the report. These were the Consolidated Vacuum Corporation (now Bendix Vacuum Division) Models GTC-004 and GTC-005, and the Fredericks Model 2B. Reliability over this period was 0.84.

Beginning in 1967, swing arm vacuum probes were replaced with a model developed and manufactured by Fredericks for the Boeing Company for application of the swing arm lines. The model number of the probe is 2167 (see Figure on Page 9). The unit is miniaturized with a connector with four pins plated with gold. Since installation of the improved probe, no known failures of these probes have occurred at Complex 39 at Cape Kennedy.

5.1.1.5 Review of the Test Data

A search was made of company owned test data (via Inspection Reports) for vacuum probe discrepancies on propellant lines returned by the Boeing Company to AMETEK/Straza for modification.

TABLE I

Part Number	Manufacturer	Number Rejected	Possible Cause of Failure				Notes
			Unknown	Corrosion	Broken or Missing Pins	Electrical	
GTC-005 75M12930	Consolidated Vac	1			X		Loose pin
GTC-004 75M12930	Consolidated Vac	2				X	
GTC-004 75M12930	Consolidated Vac	1	X				Described only as broken
GTC-005	Consolidated Vac	2				X	
HSE-1 and LSE-1	Consolidated Vac	75 75					Accuracy breaks down above 450 μ
75M12930	Consolidated Vac	2				X	
GTC-005 75M12930	Consolidated Vac	1	X				Described only as defective
75M12930	Consolidated Vac	3		X			
GTC-004 75M12930	Consolidated Vac	1				X	
75M12930/HSE-1	Consolidated Vac	3		X			
75M12930/HSE-1	Consolidated Vac	8				X	
75M12930/LSE-1	Consolidated Vac	1				X	

TABLE I (Continued)

Part Number	Manufacturer	Number Rejected	Possible Cause of Failure				Notes
			Unknown	Corrosion	Broken or Missing Pins	Electrical	
75M12930/HSE-1	Consolidated Vac	3		X		X	
75M12930/HSE-1	Consolidated Vac	1		X			Exterior of case broken
75M12930/HSE-1	Consolidated Vac	1		X			Guide post broken due to corrosion
75M12930/HSE-1	Consolidated Vac	1				X	Guide post broken off
75M12930/HSE-1	Consolidated Vac	1					Leaked through top of probe
75M12930/HSE-1	Consolidated Vac	3					Leaked through seams of case
2B TELVAC	Fredericks	1	X				Described only as defective
2B TELVAC	Fredericks	1	X				Described only as defective
Unknown	Fredericks	6		X			
6TC-004 75M12930/HSE	Consolidated Vac	2		X		X	
75M12930/HSE	Consolidated Vac	1		X			Leaked through pins
75M12930	Consolidated Vac	2		X		X	

TABLE I (Continued)

Part Number	Manufacturer	Number Rejected	Possible Cause of Failure				Notes
			Unknown	Corrosion	Broken or Missing Pins	Electrical	
75M1 2930/HSE-1	Consolidated Vac	1					Leaked through body Manufacturer defect
75M1 2930/LSE-1	Consolidated Vac	1				X	
75M1 2930/LSE-1	Consolidated Vac	1		X			
75M1 2930/LSE-1	Consolidated Vac	2				X	
75M1 2930/HSE	Consolidated Vac	2		X			
75M1 2930/HSE	Consolidated Vac	1	X				Described only as unknown
75M1 2930/LSE-1	Consolidated Vac	1				X	
CVC-005	Consolidated Vac	8				X	Periodically failing lack of shock spec.
GTC-005 75M1 2930/LSE	Consolidated Vac	1				X	
75M1 2930	Consolidated Vac	10				X	
GTC-004 75M1 7762	Consolidated Vac	7				X	

TABLE I (Continued)

Part Number	Manufacturer	Number Rejected	Possible Cause of Failure				Notes
			Unknown	Corrosion	Broken or Missing Pins	Electrical	
GTC-005 75M12930	Consolidated Vac	2				X	
GTC-004 75M17762	Consolidated Vac	1			X		
GTC-004 75M12930	Consolidated Vac	1			X		
GTC-004 75M12930	Consolidated Vac	3		X		X	
GTC-005 75M12930	Consolidated Vac	3				X	
11M00345	Consolidated Vac	1				X	Heater wire burned out
GTC-005 75M12930	Consolidated Vac	2				X	
75M12930	Consolidated Vac	2				X	
GTC-004	Consolidated Vac	3		X			
GTC-004	Consolidated Vac	3				X	
GTC-004	Consolidated Vac	3				X	
GTC-004	Consolidated Vac	1					Probe not effective with pumping procedure
TOTAL		264	5	29	3	75	

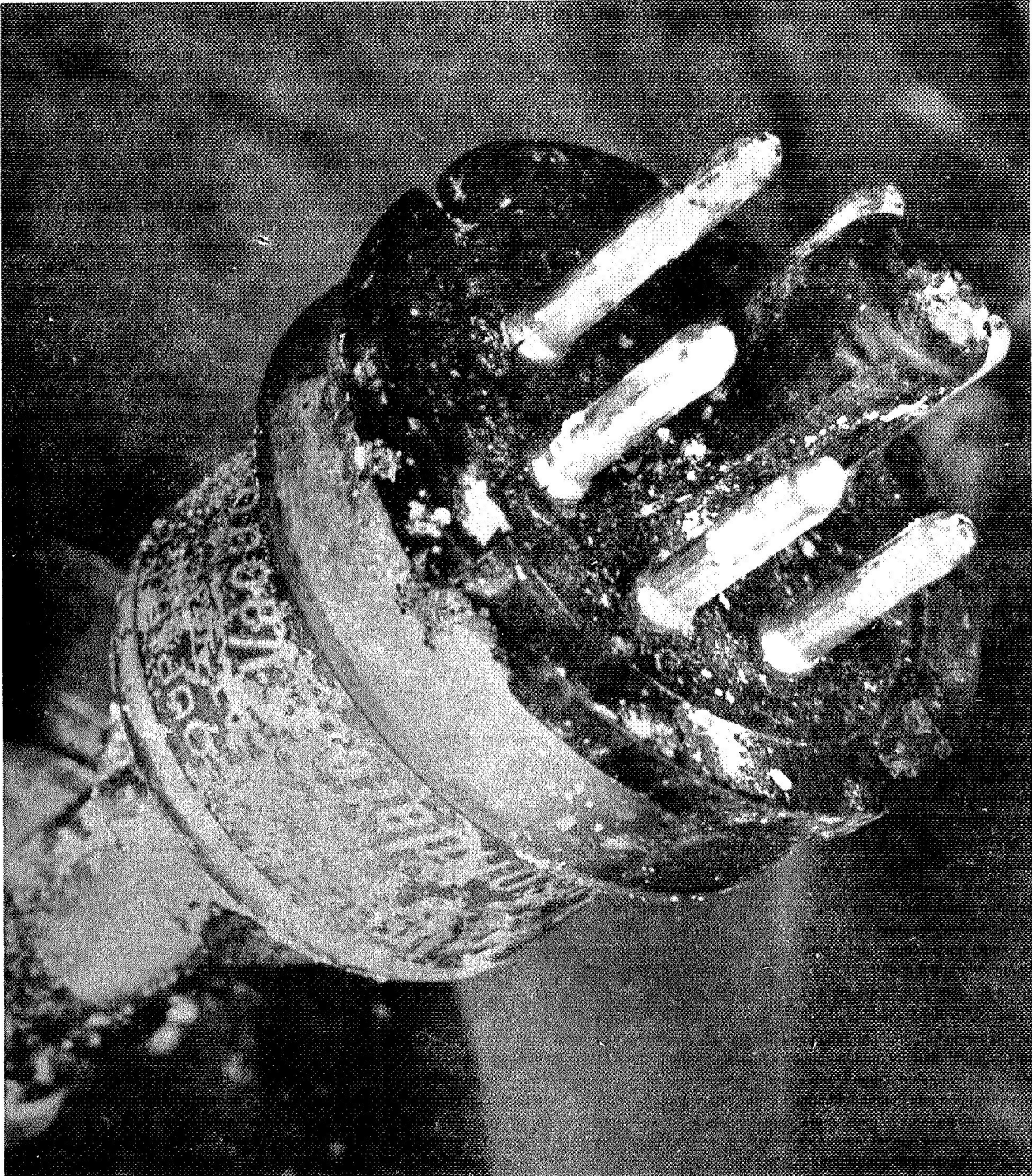


Figure 7. The Picture Shows the Effect of Corrosion on an Unprotected Thermocouple Gauge When Installed at Cape Kennedy.

Table II is a listing of probe deficiencies recorded. Of 45 rejected probes out of a total of 280, 33 were rejected for excessive corrosion of the connector pins, 6 leaked through the pins when tested with a helium mass spectrometer, 2 had failed electrically and 4 had damaged pins or missing center posts. The probe being used was the GT-004 manufactured by Consolidated Vacuum Corporation, now a subsidiary of Bendix. Since this time the company has developed a probe with a stainless steel case and a miniaturized connector. Reliability established from these reports was 0.840.

Several test reports were obtained from the Kennedy Space Center Document Section covering tests performed on vacuum probes manufactured by various companies. These reports are:

- A. Design verification test report for Saturn S-II Components — LH₂ and LO₂ Feed and Vent Lines Contract No. NAS 7-200, Solar S.O. 6-1834-9 R68H-1501
- B. Test Report TR 4-58-3-D, Fredericks Company Model 2A-M-B, Thermocouple Vacuum Gauges (Special)
- C. TR-494-D Test Report, Hastings-Raydist Inc., Vacuum Sensing Element Model DV-36, Vacuum Gauge Indicator Model VT-6X, NASA Drawing Number 10466109

The Solar Report contains test results on the Cryolab Part No. GT3-008-5T3 and the Fredericks Part No. 2167 and Part No. 2A-M. Test results for other models were the Fredericks 2A-M-B and the Hastings-Raydist DV-36. No direct comparative data can be obtained from these reports because of variations in test approach. However, all units passed the tests except for low temperature (-65°F) and a small deviation out of specification as the micron level increased. Without considering the environmental conditions found at the Space Center all units would function satisfactorily as a vacuum level indicator from 1 to 1,000 microns. It should be noted in the Solar report that during the vacuum decay test, variations as large as 15 microns were encountered between the various probes with the final readings as follows:

	Micron Readings <u>After 1500 Hours</u>
Fredericks 2 AM	43.0
Fredericks 2167	29.5
Cryolab GT3-008-5T3	*44/44

*Dual element gage

The following discrepancies and/or failures on Thermocouple Probes were noted on receiving inspections of Boeing Propellant lines returned for modification.

TABLE II

AMETEK/Straza P/N	Leaked Thru Pins	Corroded Pins	Electrical Failure	Pins Damaged	Center Post Pins Missing
8-030159		4		1	
8-030158	1	3			
8-030194		1	1		
8-030147	1	3			
8-030156	1	1			
8-030146		3			
8-030154		1			
8-030155		1			
8-030188	1	3			
8-030189		6			*1
8-030190	1	3			*1
8-030191		2		1	
8-030192		1			
TOTALS	6	33	2	2	2

NOTE: Total of 281 received.

* Center pins in both probes.

No standard was used for absolute measurement of duct pressure, and therefore data is of interest only for comparison of relative values. Also while temperature was recorded no effort was made to relate data to a standard temperature. A sample of six Fredericks Part No. 2167 vacuum probes were selected from stores at AMETEK/Straza and mounted in a common manifold and tested at various pressures up to 200 microns reading the output of each probe with the same vacuum gage meter. Two of the probes had a deviation of 10% at 200 microns while the remaining six were within 1% of each other. No absolute measurement of the true vacuum pressure was taken.

No firm conclusions could be derived from the study of the test data available from the various test reports, except for the indication of deviation from comparative data and a tendency for increasing deviation as pressure increased. However, these variations are not great enough to disqualify a thermocouple vacuum probe as a pressure indicator in the range from 1 to 1,000 microns.

5.1.2 Product Review

5.1.2.1 State-of-the-Art Investigation

A review of the literature on vacuum technology was made for devices capable of measuring low pressures in the 1 to 1000 micron range. The following is a list of such devices.

- A. Manometers (Liquid)
 - (1) Rayleigh Gauge
 - (2) McLeod Gauge
- B. Manometer (Mechanical)
- C. Viscosity Manometer
 - (1) Decrement Type
 - (2) Rotating Disk or Molecular
- D. Radiometer
 - (1) Crooke's
 - (2) Knudsen
- E. Heat Conductivity Gauges
 - (1) Thermocouple gauges
 - (2) Resistance Gauges (Pirani)

F. Ionization Gauges

G. Piezoelectric Oscillator Manometer

Other low pressure devices are available for measurements in the ultrahigh vacuum range but were not considered applicable to the pressure range of interest in this study program. Ionization gauges are mentioned as a matter of interest.

Liquid Manometers — A Rayleigh gauge consists of glass bulbs connected barometrically by a U-tube filled with mercury which is supplied from a reservoir. In operation one bulb is pumped with a good vacuum and the other is connected to the vacuum system to be tested. The difference in height of the mercury in the two bulbs is proportional to the pressure. With a mirror arrangement, sensitivity to 1 micron can be achieved. This is basically a laboratory device and is too fragile for field application. Other disadvantages are the requirements for a vacuum pump and the danger of introducing mercury or other liquid into the vacuum jacket. It will not stand sudden loss of pressure.

The McLeod Gauge suffers from the same disadvantages as the Rayleigh type gauge, but is mentioned because of its importance in vacuum measurement, being considered one of two absolute low pressure measurement devices. The principle of operation is the compression of the gas to be measured to an accurately known ratio and then determining the pressure with a conventional U-tube manometer principle. The operating range of a given McLeod gauge is approximately three decades. These gauges are used by most manufacturers of thermocouple probes to calibrate their master gauges used for the calibration of production probes. Only the volume of the McLeod gauge can be verified by the National Bureau of Standards (NBS). For this reason there is presently no standard available for the measurement of low pressure.

Mechanical manometers are useful in the rough vacuum range and use Bourdon tubes, simple diaphragms and aneroid bellows as sensing elements. These devices with mechanical linkage can be used down to 100 microns but their accuracy is not too satisfactory below 1000 microns. Because of the limitation in operating range these devices are not applicable for use at Cape Kennedy.

An instrument known as Baratron has been introduced which has an operating range from 10^{-2} microns to 10^{-6} microns. Its basic principle is the change in capacitance of a taut metal diaphragm exposed to the vacuum system to be measured. The

unit is fairly rugged and can be read remotely (up to 1,000 feet). Presently these units are rather expensive costing about 10 times a thermocouple system.

Viscosity manometers are of two types, the decrement and rotating disk. As their name implies, the basic principle is the effect of the viscosity of a gas on a member in motion. In the decrement gauge, the rate of decrease of amplitude of a vibrating member is used to determine pressure. The decrement viscosity manometer is a laboratory device and is susceptible to vibration. A commercial model of the rotating disk viscosity manometer is manufactured by the General Electric Company. It contains a cylindrical rotor rotating at 3600 RPM driving a restrained rotor which is mechanically connected to an output pointer. It operates in the range from 1 to 2×10^3 microns. Its main disadvantage is that it indicates the output reading at the same location where the pressure is sensed. Above 300 microns the unit operates as a windage gauge instead of a viscosity meter.

The Crooke's radiometer demonstrates the operating principle of this type of instrument, the Knudsen gauge however, being the more important. The radiometer consists of vanes darkened on one side with lamp black. The vanes are mounted on a vertical axis free to rotate. A heat or light source brought near the vanes will cause them to rotate, the kinetic energy of the molecules rebounding from the hotter dark side being higher than the molecules rebounding from the cooler bright side of the vane. Knudsen used this principle to construct a vacuum gauge which with the McLeod gauge is considered to be absolute since all quantities involved can be measured directly. The Knudsen gauge is useful in measuring pressure to not more than 500 microns and is very fragile being useful only as a laboratory instrument.

The heat conductivity gauges include the thermocouple probe which has been described earlier. All heat conductivity gauges operate on the principle of the strong dependence of heat transfer in a gas on the pressure in the range from 1 to 10^4 microns. At pressures below 1 micron heat transfer by radiation and conduction are the dominant effects. Above 10^4 microns, heat transfer by conduction is the dominant effect. Sensitivity varies with wire size, size of housing and heater wire temperature.

Thermocouple gauges are relatively rugged and are low in cost. While variation occurs in output these devices are suitable for application in vacuum jacketed lines, particularly if a calibration check can be made periodically.

The Pirani gauge is a heat conductivity device with a temperature sensitive resistor enclosed in the vacuum system and a compensating resistor sealed in a reference vacuum. A bridge circuit is employed to measure the voltage required to maintain the element at a constant temperature. A Pirani gauge operates in the same range of pressure as the thermocouple type. Problems have been encountered with the maintaining of the reference vacuum but improvements have been made.

Ionization gauges operate in the pressure range below 1 micron and are not applicable to this study program. However, ionization gauges are widely used in the vacuum industry along with thermocouple probes. It operates on the principle of ionizing gas with a stream of electrons and measuring the ion current. This current is proportional to gas density over a wide pressure range.

An interesting device described by Pacey is a piezoelectric manometer employing an oscillating crystal in the vacuum system. The device is linear from atmosphere down to 100 microns. Its principle of operation is based on the damping effect of the gas molecules on the quartz crystal, with the system requiring more power as the pressure increases.

Other types of vacuum gauges employ radioactive sources, the most commonly known being the Alphatron. These instruments are quite expensive. Operation depends on the ionization of gas molecules contained in the vacuum system.

In summary, of all vacuum gauges surveyed the thermocouple probe most closely fits the requirements at Cape Kennedy from the standpoint of cost, ruggedness, and simplicity of operation. Improvement can be made and is being made by some companies to improve reliability to meet the environment at the Cape.

5.1.2.2 Hardware Investigation

A search was made for manufacturers of vacuum gauges. Literature was obtained for all types of gauges but thermocouple probes were of primary interest. Twenty-four companies were contacted and seven of these were visited. About fifty percent of the companies offering thermocouple probes do not make their own but procure them from such companies as Hastings-Raydist or Hughes Aircraft Company. Companies visited were The Fredericks Company, Vacuum Instrument Corporation, Vactronics, General Electric, Bendix Vacuum Division (formerly CVC), Hughes Aircraft, and Cryolab. The people contacted at these companies were very helpful and cooperative, giving their time to answer any questions and describing their manufacturing procedures for the production of thermocouples. Arrangements

could not be made to visit Hastings-Raydist due to the proprietary nature of their Thermopile* type probe, and Veeco did not have personnel available at the time of the visit. However, it was learned that Veeco does not make their own probes but are purchased from Hastings-Raydist. Hastings-Raydist was kind enough to send some published literature on the operation and calibration of thermocouple probes.

In general, thermocouple probe manufacture is a small part of a company's product line with production on "as required" basis. Most of the companies visited had developed specialized equipment for the cutting and welding of the thermocouple to the mounting posts to maintain close control over the total resistance of the thermocouple wires and heater wires. Companies such as Fredericks and Bendix have strong Quality Control departments, while at some of the smaller companies, such as Vacuum Instrument Corporation, such Quality Control is limited to "as needed" basis. Bendix Vacuum, Hastings-Raydist, Fredericks and Cryolab have developed thermocouple probes for specific application under conditions found at Cape Kennedy. Other companies such as Vacuum Instrument Corporation have developed probes with stainless steel envelopes to resist corrosion.

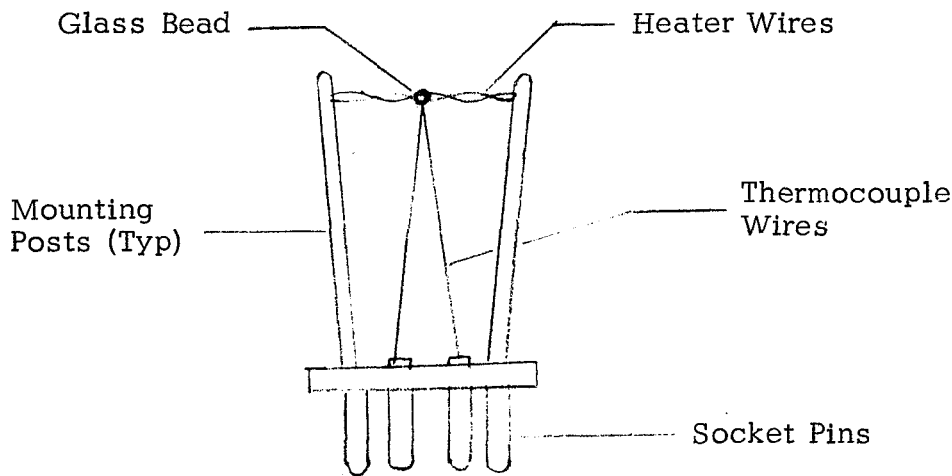
Except for Cryolab, most companies perform a one or two point calibration measuring output at very low pressures (1 micron or less) and at a point between 50 and 200 microns for a 1,000 micron scale device. Cryolab calibrates their probes at ten points to full scale. A master gauge is used for calibration of production line gauges. This gauge is periodically recalibrated with a McLeod gauge at specified pressures. Cryolab and Fredericks produce thermocouple gauges which are completely interchangeable with any of their readout instruments, while General Electric, Hastings-Raydist, Hughes Aircraft, and Bendix furnish a current value imprinted on the gauge tube. The readout instruments should be adjusted to this value whenever gauge tubes are changed to ensure correct readout. However, these companies do make batch selections of thermocouple probes having the same current requirements allowing a multiple gauge system to be read by one readout instrument without requiring adjustment of the heater current. Reorders of thermocouple probes are required to have the heater current specified to match the existing probes in use. Any deviations of heater current from the specified value causes large deviations from true pressure readings.

There is no standard presently for the measurement of low pressure directly traceable to the NBS. McLeod gauges are certified only for volumes. A committee of the American Vacuum Society,

*Trademark

headed by Thomas Connor of Bendix Vacuum Division, is working on this problem. Because of the lack of standards and the numerous variables encountered in the pressure range of 1 to 1000 microns such as gas composition, condensible gasses, system contamination and effects of temperature, thermocouple probes at best should be considered a pressure indicator and not a precision device when applied in a field application.

Effects of vibration and shock were discussed with the various suppliers. Earlier models of vacuum probes were very susceptible to vibration damage. The figure on Page 24 is a typical thermocouple probe. The figure on Page 25 shows the typical failure mode encountered. Breakage occurs in the heat affected zone of the fine heater or thermocouple wire. While the wires themselves, because of their low mass, see little shock or vibration, the heavier mounting posts do. Consequently, any heater or thermocouple wire tautly stretched between these posts will be more prone to fail under vibration or shock condition. Cryolab manufactures their probes with loose wires with the result of the unit successfully passing vibration tests conducted by Solar (Report No. R684-1501) at a sinusoidal level of 25 g's. Total vibration time for all conditions was 12 hours and 20 minutes. Bendix (formerly CVC) has had in the past a field problem at Complex 34 with their GT-005 gauge due to electrical failures as reported by the UCR's, with a number of electrical failures after each launch. Construction of the Bendix gauge is shown below.



NOT TO SCALE

Figure 8. Construction of Bendix Gauge

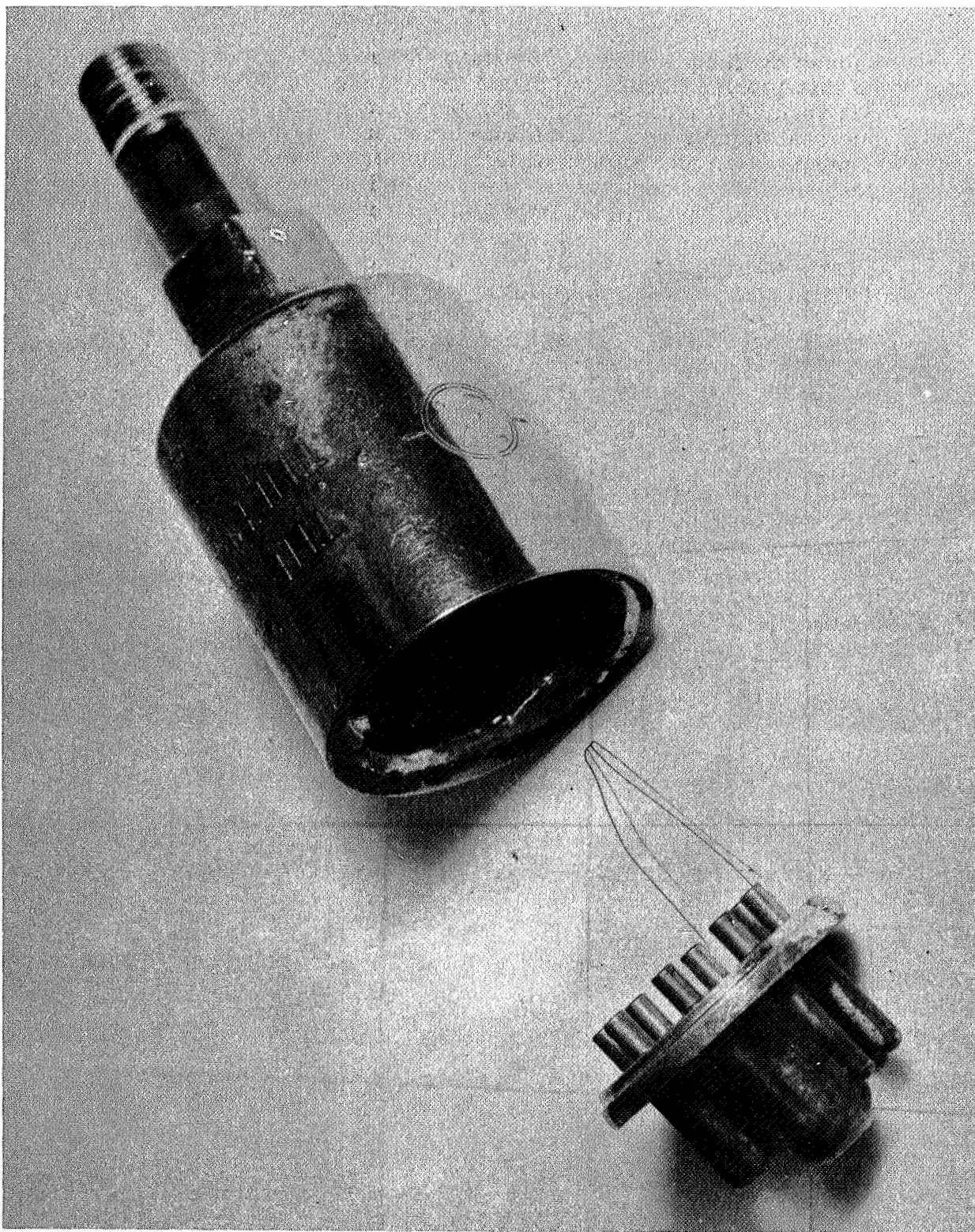


Figure 9. Typical Construction of a Thermocouple Probe.

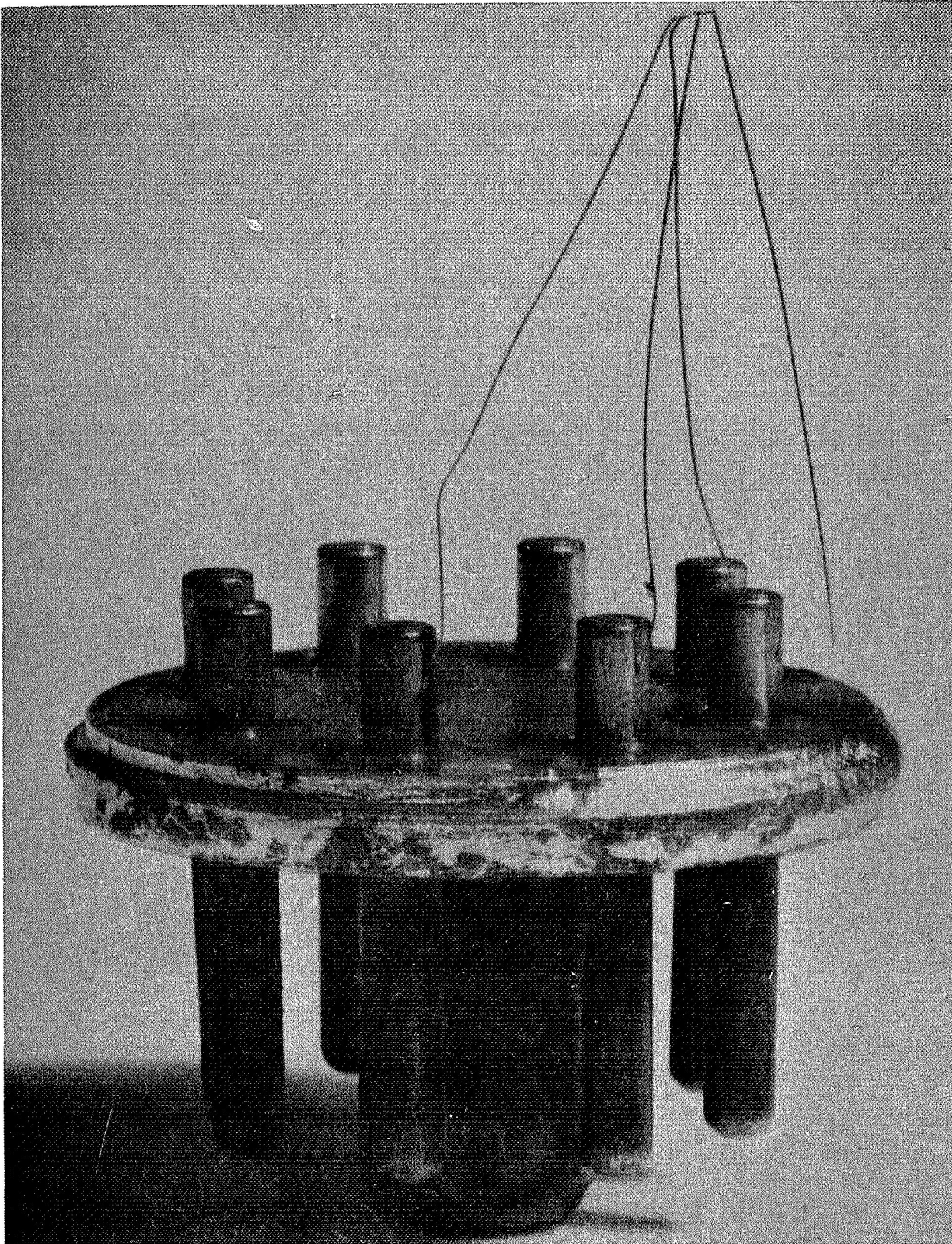


Figure10. Enlarged View of the Probe Shows the Mode of Failure as Breakage of the Wire at the Heat Affected Zone on the Mounting Post.

The heater wires are stretched between two highposts, while the thermocouple wires are connected to two low posts. In this type of construction, if the mounting posts go into resonant frequency, the fragile heater wires are exposed to relatively high stresses causing failure.

Difficulty has been encountered by several companies during vibration tests with the failure of the 1/8-inch pipe stem used for connecting the unit to the vacuum system. This condition has been improved with the introduction of the miniaturized probe by Fredericks and Cryolab. The effect is a lowering of the center of mass reducing the induced vibration loads on the stem.

The problem of corrosion has been attacked with the introduction of miniaturized connectors with gold-plated pins. A protective cover is furnished with the Cryolab model. Protection from mechanical damage is also afforded by this connector since the pins are protected by the shell of the connector (see figure on Page 2).

In summary, advancements are being made in the vacuum industry to improve the ruggedness and operating characteristics of thermocouple type vacuum probes, notably two companies, Cryolab and Fredericks, have designed probes for specific application at the Cape Kennedy Space Center. The Fredericks probe is presently used on the swing arm lines at Complex 39 with no known failures to date. Corrosion has been minimized by the use of corrosive resistant metals and the introduction of connectors with gold-plated pins. The shell of the connector offers protection against mechanical damage. Protective waterproof covers are being supplied to protect the connector pins from dirt and accumulation of airborne salt. Protection against shock and vibration is being afforded by miniaturizing the thermocouple envelope and by protecting the heater and thermocouple wires from vibration imposed stresses through the mounting posts. If the thermocouples are used as a pressure indicator to determine the need for repump at some pressure level consistent with the cryopumping abilities of the vacuum jacketed lines, then they will perform adequately. To ensure a confidence level, some means should be developed for a periodic recalibration of the probes without the loss of the vacuum integrity in the vacuum jacket of the insulated propellant lines. Long term reliability is improved by the introduction of a dual element thermocouple probe such as produced by Cryolab. Since electrical failure is normally due to breakage of the thermocouple or heating wire at one of the four mounting posts in a single element, cycle life expectancy could be expected to be extended by approximately 70% for a dual element gauge such as the Cryolab unit.

5.1.3

Design Phase

The design evaluation is divided into three parts:

- A. Design consideration for improving performance of the thermocouple probes for employment at the Space Center.
- B. Methods for periodic recalibrations of vacuum jacketed lines without losing vacuum integrity.
- C. The feasibility study of an acoustical type vacuum gauge based on the initial work of Pacey.

5.1.3.1

Thermocouple Probe

The thermocouple probe shall function as a pressure sensing device when installed integrally with the vacuum annulus in cryogenic storage and transfer system. The thermocouple probe with associated readout equipment shall have an operating range from 1 to 1,000 microns with provisions on the readout meter to indicate atmospheric pressure. The accuracy of the reading of the vacuum probe consistent with field usage shall agree with those from a calibration standard to within $\pm 10\%$ of full scale (1,000 microns) above 500 microns, $\pm 10\%$ of reading between 100 and 500 microns, and ± 5 microns below 100 microns. This accuracy is in agreement with the requirements found in the field where repump occurs between 100 and 500 microns and also takes into account the non-linearity of the thermocouple probe at its lower and upper ranges. The shell of the probe will withstand an internal pressure of 75 psig. Maximum internal leakage shall not exceed 1×10^{-7} scc of He/sec.

Operating life shall be for a period of five years with the unit capable of leakage free performance during all conditions of test, checkout, pre-launch operations and launch. During this period, the unit shall be capable of trouble free operation under the following conditions:

- A. Twenty pressure cycles from high vacuum to atmosphere to high vacuum at the rate of four cycles per year. At all other times, the unit shall be at a high vacuum under static condition.
- B. The unit shall be intermittently activated electrically 100 times for readout purposes. Maximum length of time of applied power at any one time shall not exceed one hour.

For corrosion resistance, the body should be of 316 or 316L stainless steel to meet the corrosive atmosphere found at Cape Kennedy. Wall thickness should not be less than 0.030 inch for long term installation.

Due to the effects of vibration and shock, the center of mass should be as low as possible in relation to the mounting point and as light as possible to prevent breakage at the mounting stem. See the figure on Page 29 for the recommended configuration. A rubber shock bumper should be placed around the body of the unit to prevent damage from accidental bumping.

The internal construction should be such that rapid evacuation or pressurization of the vacuum annulus will not cause premature breakage of the heater or thermocouple wires. This can be accomplished by means of a perforated plate between the active elements and the stem of the thermocouple probe. Heater and thermocouple wires should be 1 mil or less to minimize the effects of vibration. These wires should not be stretched taut to allow mounting post vibration to impact high stresses on the wire at the point of attachment. The junction of the thermocouple should be protected by a glass lead to minimize change in output due to oxidation and/or contamination of the thermocouple junction. Because electrical failure is most likely to occur at the heat affected zone where the wires are spot welded to the mounting post, a small amount of epoxy or similar material should be applied at this point to increase its mechanical strength.

The electrical connector should have gold-plated pins to resist effects of corrosion. Either a threaded connector or a twist and lock type are recommended, with a water tight protective cover supplied with the unit. This protective cover should be permanently attached to the probe by means of a chain. To reduce chances of mechanical damage, the connector could have button type contacts. This would also reduce the chance of breaking the glass seal around the feed through pins causing the unit to leak.

The thermocouple probe should be able to withstand the environmental conditions as set forth in the KSC document KSC-STD-164D, Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy.

Maximum sinusoidal vibration shall be 30 g's and the maximum shock shall be 30 g's half sine with a duration of 2 milliseconds. Based on the design considerations a preliminary procurement specification has been prepared and is included as Appendix A in this report.

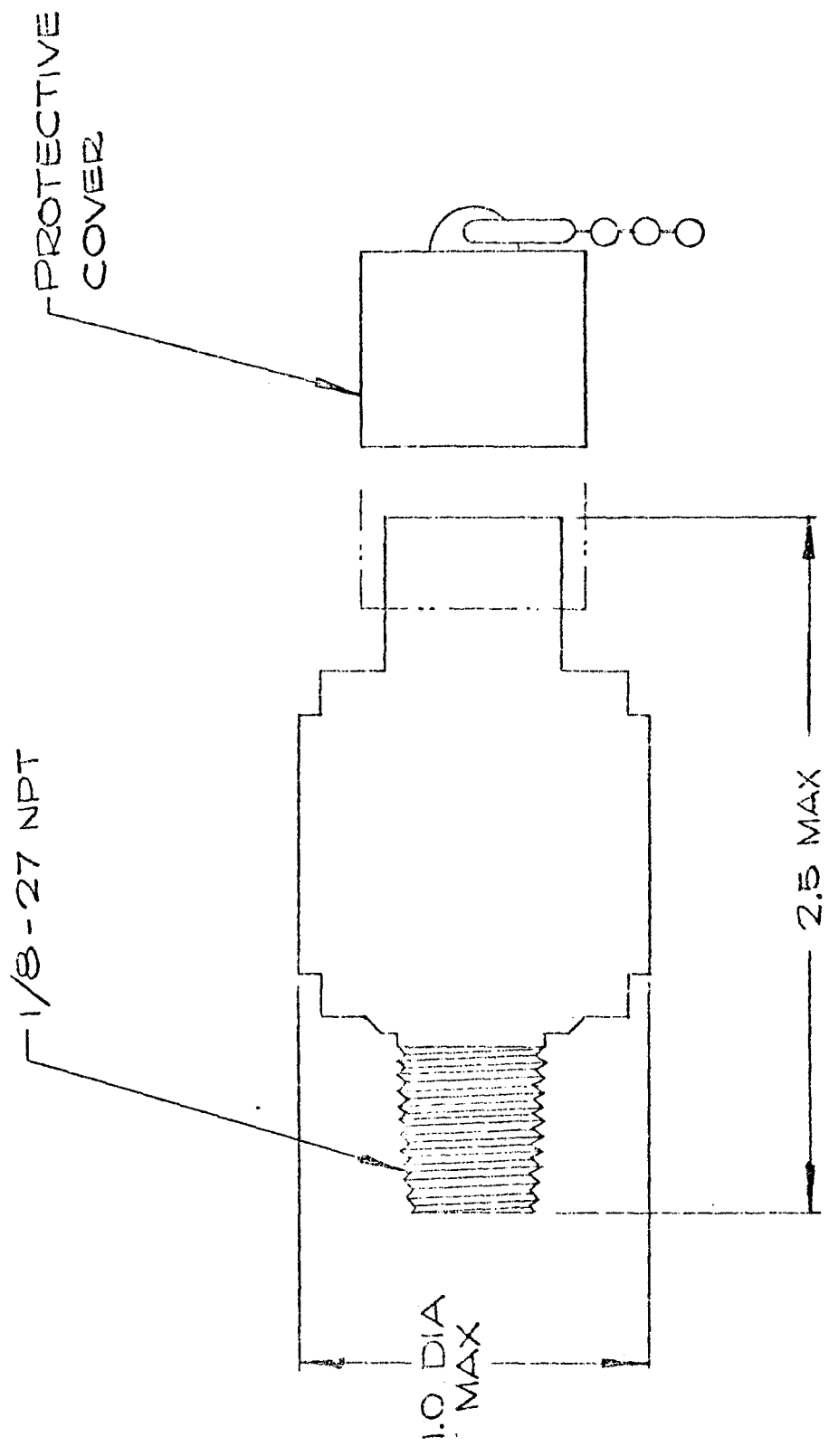


FIGURE 11
GAUGE TUBE, VACUUM
ENVELOPE DIMENSIONS

4052-1

Three companies presently most closely meet the design requirements set forth in this report. These companies are:

- A. Fredericks
- B. Cryolab
- C. Hastings-Raydist

While none meet all suggested improvements, those steps to enhance reliability can be obtained by each without any great change in design criteria. It is planned that units be procured from each of the companies and evaluated as set forth in the test plan prepared for the Phase II test program.

Reliability of thermocouple probes at Cape Kennedy has been 0.84 over the past several years as determined from UCR's and company test data on propellant swing arm lines returned from Cape Kennedy by Boeing for modification. State-of-the-art reliability with the advent of the new Fredericks gauge is 0.919. With improvement by design changes, failures can be reduced to 10 out of 261 instead of 45 out of 261 with a resultant preliminary reliability of 0.964.

The following is a detailed breakdown of failures or discrepancies and the expected reduction to be achieved.

	<u>Cause of Failures</u>				
	<u>Leakage</u>	<u>Corrosion</u>	<u>Electrical</u>	<u>Unk.</u>	<u>Missing Pins</u>
Total Existing	6	33	2	2	2
Preliminary Reliability Goal	0	6	2	2	0

Calculation — 281 Items

$$\text{Existing} - \frac{45 \text{ Failures}}{281 \text{ Items}} = \frac{281-45}{281} = \frac{236}{281} = 0.840$$

$$\text{Preliminary Reliability Goal} - \frac{10 \text{ Failures}}{281 \text{ Items}} = \frac{281-10}{281} = \frac{271}{281} = 0.9644$$

Field personnel presently have no means of knowing whether a vacuum gauge is operating properly over long periods of time unless a total failure is apparent. Means should be provided for recalibration of thermocouple gauges without losing the vacuum integrity of the annulus of the propellant line with subsequent repumping of the line.

A recommended recalibration period is once every six months. Several schemes are presented along with advantages and disadvantages to accomplish this recalibration without re-evacuation of the total system. One of these systems should be adopted for any future launch umbilical tower with vacuum jacketed lines at Cape Kennedy. Any of these systems should have a valve between the gauge and the vacuum annulus with pump out provision to remove gas introduced into the vacuum gauge. Pump out would be accomplished by a small portable sorption pump which requires no power to operate and is light in weight. A sorption pump is a device employing a liquid nitrogen cold trap filled with a "gettering" material such as zeolite, to absorb and adsorb the gas molecules. Such a device is limited in the amount of gas it can absorb by the volume and temperature of the gettering material.

5.1.3.2 Dismountable Readout Thermocouple

In this system only one thermocouple is used for all the lines, being removed from the line annulus valve after readout. In operation the sorption pump with the vacuum gauge would be attached to the line by means of a valve similar to the Cryolab (see the figure on Page 32). The sorption pump valve would then be opened and the small volume contained in the valve body evacuated. The sorption valve is then closed and the annulus valve opened. Annulus pressure is read and the annulus valve closed. The sorption pump and vacuum gauges are then removed.

The advantages and disadvantages of the dismountable readout thermocouple concept are listed on the following page.

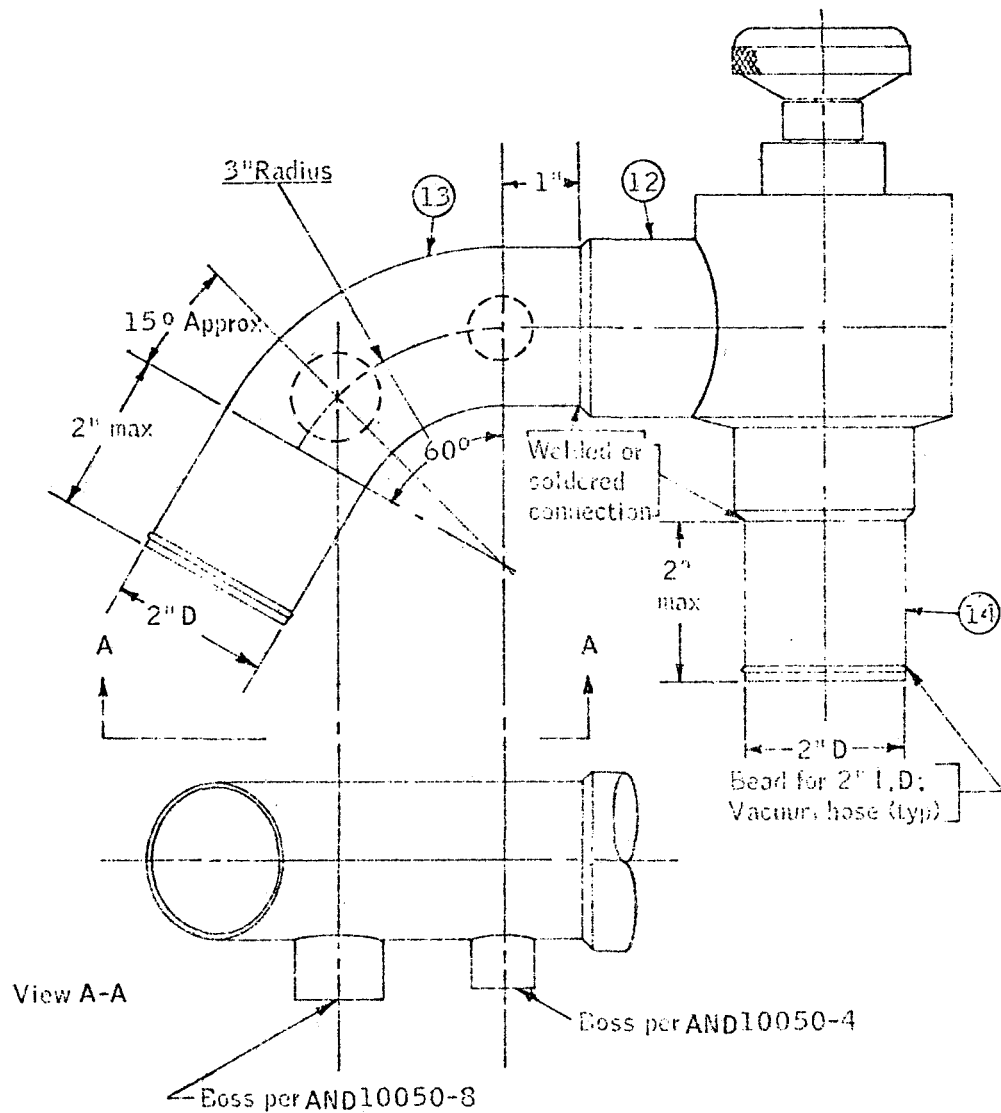
Advantages

1. Single Gauge
2. Calibrated in Lab
3. Not prone to physical damage from vibration
4. Portable
5. Less costly than double-acting valve scheme

Disadvantages

1. Increased operator error
2. LN₂ Supply required
3. Increased chance of leakage through valve O-ring.

P/N 7257-5R3



				UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:			DATE
				FRACTIONS	DECIMALS	ANGLES	DRAWN
B Add pg. 2 with -5R2 & -5R3				UNDER 1" $\pm 1/64$.X ± 0.050		CHK
A Redrawn to remove 7252-5T1				1" TO 2" $\pm 1/32$.XX ± 0.015	$\pm 1^\circ$	ENG
SYM REVISION				OVER 2" $\pm 1/16$.XXX ± 0.007		
BY DATE				BREAK SHARP EDGES 0.007 MAX; ALL MACHINED SURFACES			

Figure 12. Pump-down and Seal-off Valve.

5.1.3.3 Vacuum Probe Installation With Double-Acting Valve

The second scheme is a permanently installed thermocouple on a double-acting valve (see figures on Pages 34 through 36) which permits sealing off the annulus for thermocouple calibration or replacement. Again a sorption pump is used to evacuate the small volume of the valve body and thermocouple. In operation the thermocouple is open to the annulus and the vacuum readings may be taken at any time. For recalibration, the sorption pump is attached to the line valve through an operator valve. The valve is evacuated and the annulus closed. Calibration or replacement is accomplished at the end of which the valve and thermocouple volume is re-evacuated and the annulus opened to the thermocouple. The sorption pump is then removed. The advantages and disadvantages of the vacuum gauge installation with a double-acting pump are listed below:

Advantages

1. Calibration capabilities
2. No pump necessary under normal conditions

Disadvantages

1. Extra sealing surface and O-ring
2. More chance for operator error
3. More susceptible to vibration and shock
4. More costly than removable gauge scheme

5.1.3.4 Present Permanent Installation

This is the existing configuration for vacuum measurement now installed in the swing arm cryogenic lines. It consists of a miniaturized thermocouple with a threaded connection (similar to the figure on Page 29) screwed in a boss which opens into the line annular space vacuum (see figure on Page 3 for typical installation). This concept keeps the number of operations required to read the vacuum to a minimum, but causes complete repump of the annulus when calibration is required or failure occurs.

Advantages

1. One shot installation
2. Minimum operator error

Disadvantages

1. No calibration after installation
2. Hard to replace with loss of vacuum integrity in annulus
3. Additional bulky repump equipment necessary
4. Subject to vibration and shock

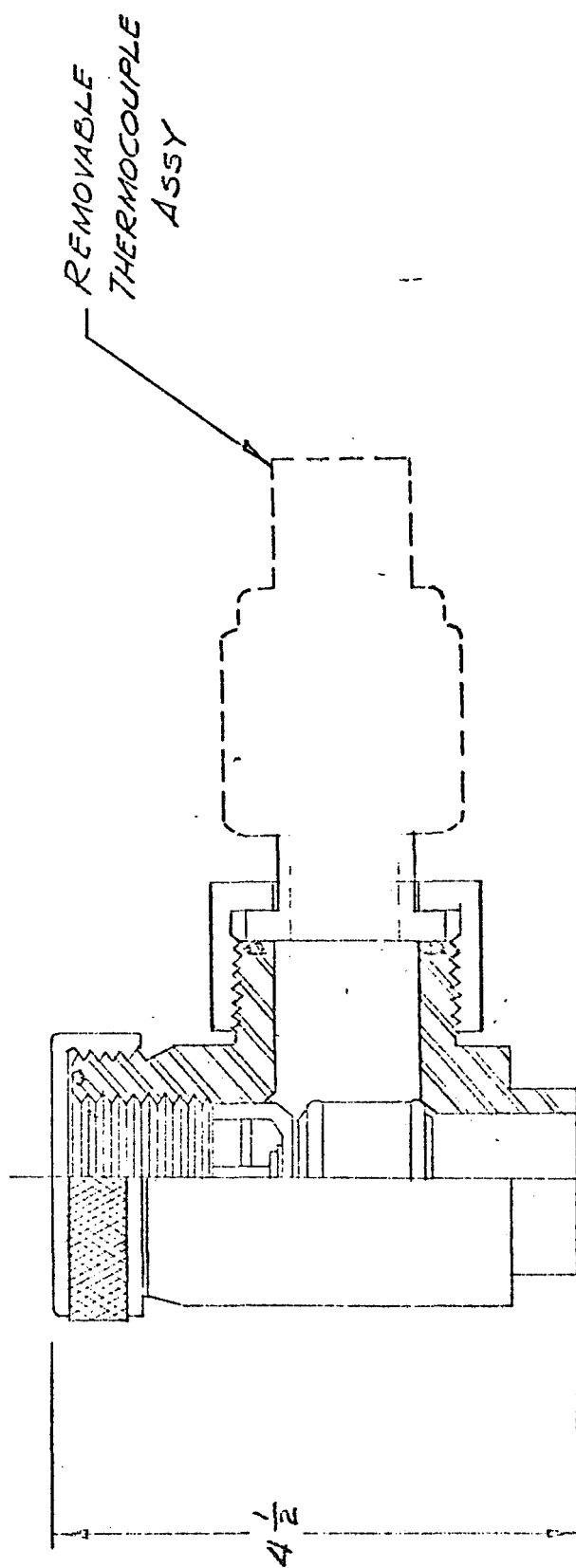


Figure 13.
DUAL PORT VACUUM SEAL-OFF VALVE
CRYOLAB P/N SV2-86-5Z1

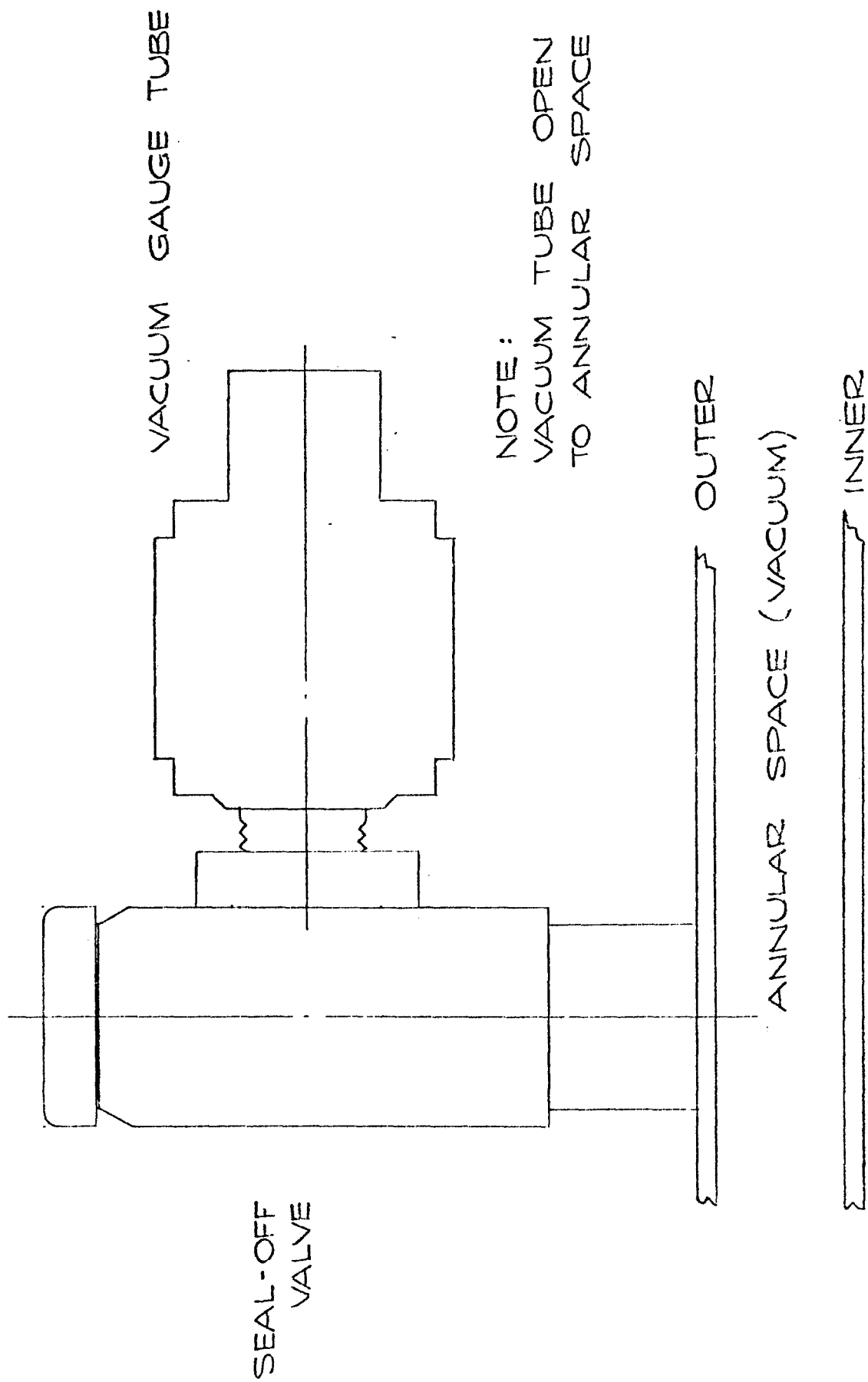


FIGURE 14

Normal Operating Position, Seal-Off Valve and Vacuum Gauge Tube

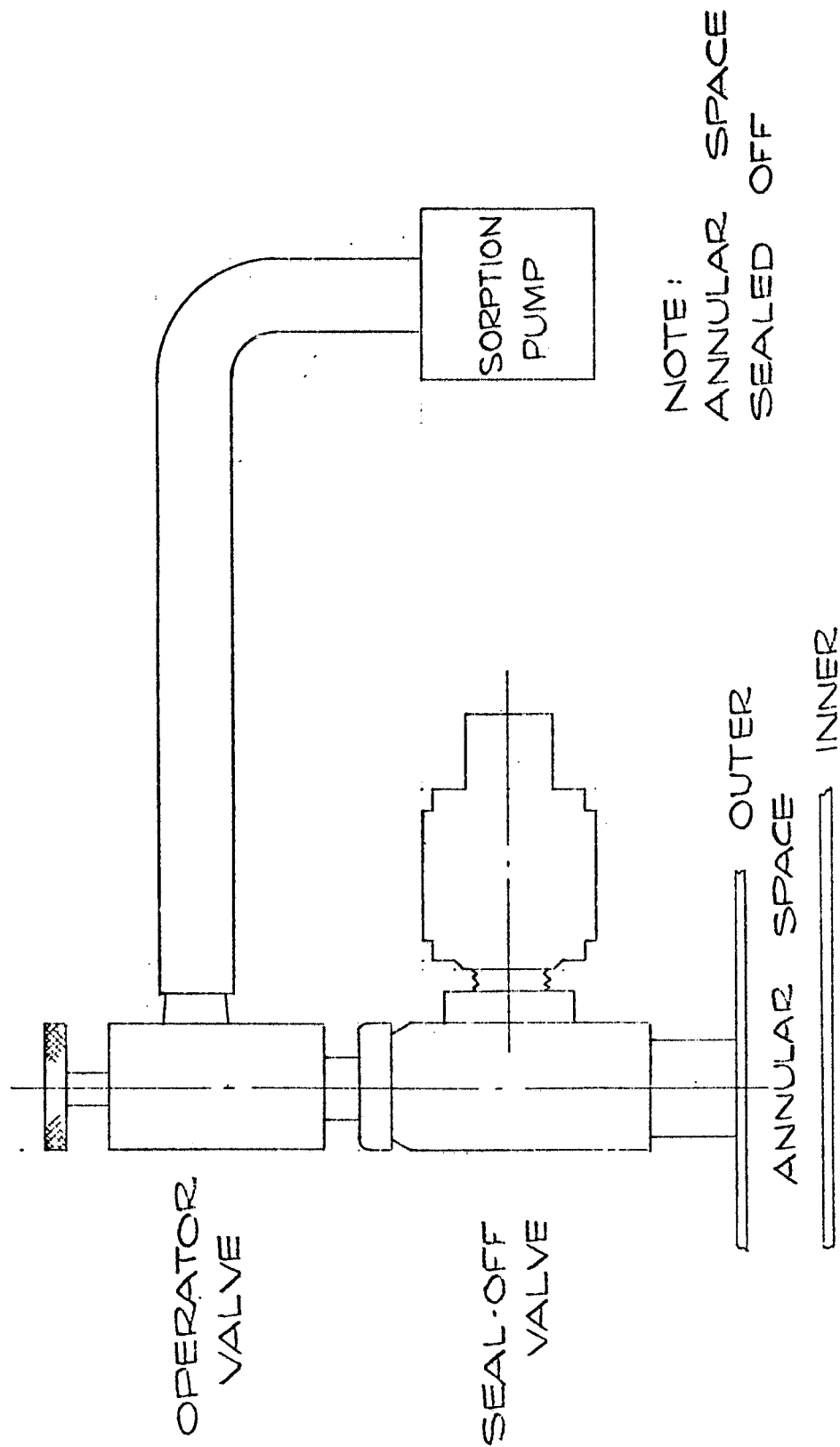


FIGURE 15

VACUUM GAUGE TUBE REPLACEMENT

5.1.3.5 Acoustical Vacuum Probe

Two more advance concepts requiring additional design evaluation and testing were considered. The first is an acoustical vacuum probe mounted externally on the vacuum jacketed line. Some initial experimental work was done as will be described later.

This is a vacuum measuring concept employing two acoustical probes facing each other. An acoustical signal is sent to the receiving probe. The speed of signal transmission between the probes is proportional to the pressure. This vacuum pressure measurement can be made continuously and with both acoustical probes external to vacuum annulus.

Advantages

1. Mounted externally
2. Reduces operator error
3. Can be calibrated

Disadvantages

1. Much higher cost
2. Must be developed

5.1.3.6 Vacuum Ion Pumps

The second concept would be the use of vacuum ion pumps which would be used to maintain a low vacuum level in the annulus of the propellant lines at all times. This device can be used as a vacuum gauge at the same time as the amount of current drawn is directly proportional to the pressure. Again, it is cautioned that such a concept would have to be fully evaluated.

Advantages

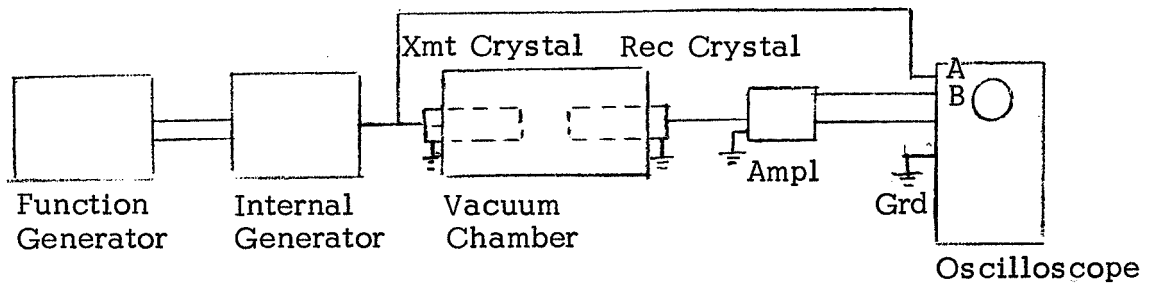
1. Continuously pumps line
2. No absorbant necessary
3. Simplifies pump down system
4. Functions as vacuum gauge

Disadvantages

1. Untested application
2. Short life if leak develops
3. Needs constant power source

5.1.3.7 Acoustical Manometer Evaluation

During the early phase of the study program some feasibility tests were performed employing various types of acoustical devices. One advantage of an acoustical device is its linearity over the total pressure range as reported by J.C. Pacey in "Vacuum". A simple test setup (as shown in the following figure) was made employing company available air acoustic probes.



Schematic for Acoustical Manometer Evaluation

Figure 16

Two acoustical probes were mounted in metal tubes with faces made of 0.010-inch material. These tubes were placed in a vacuum chamber with the two probes in line and facing each other. The transmitting probe was activated at its resonant frequency for several milliseconds.

The receiving probe picked up the transmitted signal which was amplified and the amplified signal fed to an oscilloscope. With this setup both change in amplitude of signal and time delay (dt) could be easily detected to 700 microns of pressure, at which point the signal was lost in the background noise.

A second test setup was made using smaller acoustical ceramics (see below). The same test setup was employed as in the previous test.

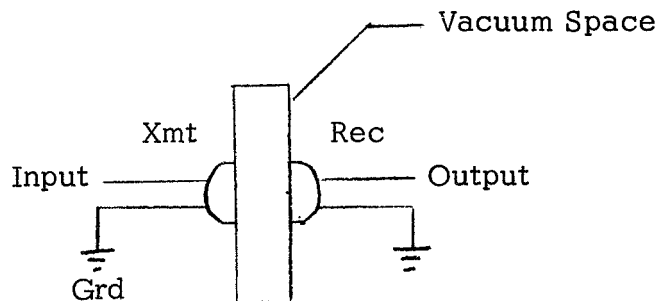


Figure 17

Results of this test were unsatisfactory for two reasons; (1) the separation between the metal path and the air path was not great enough to allow resolution of the air gap signal from the metal path signal, and (2) the input signal voltage was too low causing the unit to be less sensitive than desired. Work was stopped at this point because it becomes apparent that the thermocouple type vacuum gauge was quite satisfactory for the application.

While the initial setup was quite elaborate as far as associated equipment goes, the actual circuitry would be relatively simple. The circuit is basically a flip-flop with the receiver signal firing the transmitter and vice-versa. The pressure dependent frequency thus generated would be converted to a DC signal to be read on a meter.

5.1.3.8 Piezoelectric Vacuum Measuring Device

In conjunction with the above tests, a test was performed using a quartz crystal directly in a vacuum. The purpose was to determine the change in frequency as a function of pressure. Initially a 4.0 Mc crystal was used. A change in resonant frequency of 14 counts was noted. When a crystal with a resonant frequency of 20.0 Mc was used a count of 110 cycles was noted over the same pressure range. Testing was stopped because 20 Mc is the highest frequency available in quartz crystal oscillating in the primary mode at resonant frequency. Results indicate that crystals having higher resonant frequencies in the primary mode would be more sensitive (also more fragile) to changes in pressure.

Much design and experimental work would be required to develop such a system. However, with a successful design all critical components could be mounted outside the vacuum annulus making recalibration and replacement independent of the vacuum integrity of the line. Exploratory testing was stopped because of increased costs for the development of such a device.

5.1.3.9 Quality Assurance Program

To ensure uniform standards of each individual vacuum probe, each unit will be checked for physical dimensions and electrical continuity when received. In addition, an acceptance test shall be run to confirm conformance of each unit to the requirements of leakage and accuracy. During the Phase II testing, Quality Assurance personnel shall witness all tests.

5.1.3.10 Conclusions

The thermocouple probe is an adequate device to determine the vacuum level of the annulus space in vacuum jacketed propellant lines providing provisions are made for shock, vibration, and corrosion. Several companies have designed and manufactured vacuum probes that closely approach the requirement of the launch environment and atmospheric conditions found at Cape Kennedy. These companies are:

- A. Cryolab
- B. Fredericks
- C. Hastings-Raydist

Vacuum sensors are presently installed at inconvenient locations at Complex 39. Consideration should be given for accessibility in any new launch facility. Also a uniform maximum allowable annulus pressure should be adopted compatible with the gettering material cryopumping capabilities at which time repumping takes place. Presently this maximum allowable pressure is lower than need be.

Vacuum sensors should be mounted through some type of valving system allowing easy installation or removal of calibration and/or replacement so that complicated repump conditions are eliminated.

5.1.4 Vacuum Probe Phase II Proposal

5.1.4.1 Abstract

During the Phase I study a review was made of the required operating and field practices for the thermocouple probes at Cape Kennedy. Because of inaccessibility and difficulty of replacing the vacuum probes at the Cape, it is apparent that a unit of high reliability is necessary. Previous history shows that reliability number has been about 0.84. Failures have been chiefly due to corrosion, vibration, and shock during launch operations.

However, during vendor coordination, with approximately thirty companies contacted and nine visited, it was learned that the industry was improving its product to be more shock and corrosion resistant, with several of the companies completely knowledgeable of the problems at the Cape. Four or five companies have now produced vacuum probes with stainless steel bodies, and several have tried to improve the resistance to shock and vibration. Companies with promising units include Cryolab, Hastings-Raydist, and Fredericks. Fredericks now produces a probe that has had no known failures at Complex 39, Cape Kennedy.

Design of a vacuum probe requires a unit with a low center of gravity and a minimum body weight consistent with high corrosion resistance. Electrically, the sensor wires must be 1 mil or less and mounted in such a manner that the heavy mounting posts do not exert high tension on the sensor wires. The electrical contacts also need to be corrosion resistant and protected from the weather by a water tight screw or cover. A preliminary procurement document has been written incorporating the required design features to ensure a more reliable probe.

Preliminary Phase II planning was completed with a test plan to procure vacuum probes from three companies: Cryolab, Hastings-Raydist, and Fredericks, and to evaluate them for reliability under conditions encountered at Cape Kennedy. A life expectancy envelope was determined using an accelerated life test.

Test PlanIntroductionA. Scope

The purpose of this document is to set forth the test philosophy and methodology for verifying the performance and reliability of improved vacuum gauge probes under environmental conditions to satisfy requirements for use at Kennedy Space Center.

B. Test Philosophy

The results of the study program, The Vacuum Jacketed Umbilical Lines Technology Advancement Program undertaken by AMETEK/Straza for NASA have shown that for vacuum probes that several manufacturers have redesigned their probes to meet the more rigorous environment found at Cape Kennedy. Reliability has progressed from an initial 0.84 to a state-of-the-art 0.91, with an even better factor for probes presently installed with no known failures. Because of this increased reliability, the test program will strive to provide NASA with a greater selection of probes able to meet the stringent environmental requirements to determine the life expectancy of those probes that pass the environmental tests.

A statistically significant number of probes of each type will be selected to provide a final reliability number.

C. Item Description

The vacuum gauge probe is a pressure sensor designed to measure pressures between 1 and 1,000 microns by means of its basic element, the thermocouple. The thermocouple is heated to a constant temperature (at a known pressure) by a constant current through a heater wire or by other means, such as r.f. current through the thermocouple itself.

In operation, the heater element is maintained at an elevated temperature by passage of current from a supply source. The resultant output from the thermal junction is used as the input to an indicating meter. As the vacuum in the measuring tube improves, the heater element's temperature increases due to increasing thermal conductivity of the residual gas. This increase in temperature causes a corresponding increase in thermocouple output, with a resulting higher signal level impressed on the meter.

D. Applicable Documents

The following document will be used as a guide in testing vacuum probes:

KSC-STD-164D — Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy, dated September 17, 1964.

Test Sequence

Tests will proceed in the following sequence with all probes of each type undergoing each phase of testing.

- A. Functional (Accuracy & Leakage)
- B. Proof Pressure
- C. Salt Spray
- D. Sand and Dust
- E. Thermal
- F. Vibration
- G. Shock
- H. Accelerated Life Test

Test Procedure

A. Functional Tests

Each tube shall be mounted by its normal means and checked for verification of manufacturers' specifications operating conditions, and accuracy at room ambient temperature. Each gauge tube will be subjected to the functional tests before and after each environmental test.

(1) Accuracy

Each gauge tube will be subjected to vacuum conditions of 1,000 microns, 500 microns, 200 microns, 100 microns, 50 microns, 20 microns and 1 micron. Deviation from an absolute standard (McLeod Gauge) will be determined.

(2) Leakage

Leakage rate will be determined by means of a helium mass spectrometer and shall not exceed 1×10^7 std cc/sec of Helium.

B. Proof Pressure

The test specimens will be pressurized internally with nitrogen gas to a 150 psig.

C. Salt Fog

The test specimens will be exposed to a solution of salt, 5 parts by weight in 95 parts by weight of water, at 95°F for a period of 240 ±2 hours. The specimens will be non-operating with protective covers in place.

D. Sand and Dust

The test specimens will be exposed to sand and dust at an air velocity of 100 feet to 500 feet per minute at 77°F for a period of 2 hours. At the end of this period, the temperature will be raised to 160°F and the condition will be maintained for an additional 2 hours. The specimens will be non-operating with protective covers in place.

E. Thermal Test

Low Temperature

Each specimen will be placed in an environmental box and the temperature lowered to -65 +0/-4°F and allowed to stabilize. After the specimens are removed from the environmental box a functional test will be performed.

High Temperature

Each specimen will be exposed to an area of flame at 1400 ±100°F for a period of 10 seconds. A functional test will be performed at the end of the high temperature test.

F. Vibration

Each specimen will be vibrated in accordance with Procedure I of KSC-STD-164D.

Sinusoidal Sweep

Maximum g level for the test specimens will be 30 g's sinusoidal. The specimens will be exposed to sinusoidal vibration that is cycled at a logarithmic rate between the frequency limits of 10 and 2,000 cycles per second at the specified level. The frequency range shall be traversed once

in the direction of increasing frequency and once in the direction of decreasing frequency for a period of 20 minutes (10 minutes up and 10 minutes back). A functional test will be performed after the completion of each axis of vibration.

Random Excitation

The test specimens will be exposed to random vibration at the levels specified over a frequency range from 10 to 2,000 cps for a period of 5 minutes. The specimens will be functionally tested after each axis of vibration.

G. Shock

Each specimen will be shock tested to 30 g's with a pulse deviation of 2 ms. The pulse shape will be one-half sine wave and each specimen will be tested along both directions of three mutually perpendicular axes.

H. Accelerated Life Test (Vibration)

Since vibration is the most critical environment, outside of corrosion, contributing to vacuum probe failures, a life reliability program will be run by exposing the test specimens to more and more severe resonant frequency dwells and critical frequency random vibration (from the lowest to the highest). This test method will be used to determine the highest critical service envelope in which this unit can be used.

5.1.4.3

Documentation

A test log shall be kept by the Test Engineer, listing the following minimum information and any other deemed pertinent.

- A. Date of test and specimen identification
- B. Names of testing personnel and others present to observe the test.
- C. A brief description of the test setup.
- D. Test results, damage, conditions of specimen as compared to the condition prior to test.
- E. Any circumstances or conditions which might affect test results in any way.

Both Test Engineer and Project Engineer shall sign the test log entries after test.

Photographic evidence (Polaroid, if possible) shall be made of the specimen following each individual test. The photographs shall be identified with date, type of test, specimen identification and any unusual conditions present.

A test report which will include all foregoing information will be generated by the Project Engineer. This report will include all facts and conclusions, obvious and otherwise which the tests generated. In addition, this report will contain a section entitled "Recommendations". This section will contain the collective suggestions of AMETEK/Straza regarding further design improvements which are a result of the test program.

5.1.4.4

Procurement Plan

The procurement plan for Phase II testing is to submit a test item procurement specification to a number of vacuum probe manufacturers. A selection of three companies will be made from those offering an improved vacuum probe. Eight items will be purchased from each of the three, along with the necessary meter readout equipment.

A total of 24 probes will be purchased with a meter for each type of probe.

Hardware Procurement

<u>Vendor</u>	<u>Hardware</u>
Cryolab Company	8 Units (including 1 meter)
Hastings-Raydist Company	8 Units (including 1 meter)
Fredericks Company	8 Units (including 1 meter)

Procurement Specification

The procurement specification is a separate document and may be procured under NASA KSC 79K00112, entitled Vacuum Probes — Vacuum Jacketed Cryogenic Transfer and Storage Systems.

5.2 PHASE II PROGRAM

5.2.1 Introduction

At the completion of the Phase I Study Program for Vacuum Probes, Task V, a test program was implemented to evaluate the probes which appeared to meet the design criteria established by the Phase I study.

Eight vacuum probe specimens and one readout instrument were obtained from each of the manufacturers as proposed. These companies were:

- A. Cryolab
- B. Fredericks
- C. Hastings-Raydist

The first of the test specimens were received during the final week of July 1969 and testing began 4 August 1969 with completion of the first functional test. All testing was completed on 11 November 1969. The Phase II study contains the detail test report, conclusions and recommendations as a result of the test program.

5.2.2 Test Report

5.2.2.1 Scope

This document presents the results of tests that were performed as prescribed in the test plan and AMETEK/Straza's Test Procedure No. 8-440090 to determine whether the vacuum sensing probes satisfied the environmental and operational requirements for use on the Saturn Launch Tower. These tests were conducted during the Phase II Program for the Vacuum Jacketed Umbilical Lines Technology Advancement Study, Contract No. NAS 10-6098. The procedure followed in conducting the tests, and data obtained from them, are contained in this report.

The test sequence that was followed in conducting the tests is presented in Table III.

TABLE III.

Test Nomenclature	Paragraph	Specimens		
		Hastings Raydist	Fredericks	Cryolab
Receiving Inspection	5.2.2.4.1	8	8	8
Functional	5.2.2.4.2	8	8	8
Proof Pressure	5.2.2.4.3	8	8	8
Salt Fog	5.2.2.4.4	8	8	8
Sand and Dust	5.2.2.4.5	8	8	8
Low Temperature	5.2.2.4.6	8	8	8
High Temperature	5.2.2.4.7	1	1	1
Vibration	5.2.2.4.8	8	8	8
Shock	5.2.2.4.9	8	8	8
Accelerated Life	5.2.2.4.10	8	8	8

5.2.2.2 Item Description

Eight each of three vacuum sensing probes were tested. These were as follows:

<u>Quantity</u>	<u>Model No.</u>	<u>Manufacturer</u>
8	DV-36	Hastings-Raydist
8	2100-32	The Fredericks Co.
8	GT3-008-ST3	Cryolab Company

All units were designed to operate in the pressure range from 0 to 1,000 microns.

The Hastings-Raydist vacuum probe DV-36 is a thermocouple type with the element housed in a stainless steel case with standard 1/8-inch pipe threads. A connector with gold-plated pins affords electrical connection to the readout meter Model No. VT6B. A protective waterproof cover is furnished to protect the vacuum probe electrical connector when not in use. The Model VT6B readout meter is used in conjunction with the DV-36 vacuum probe.

The principle of operation is based on the thermopile circuit consisting of a hot junction heated by an AC current and a cold junction kept at ambient temperature by heavy mounting studs. A third thermocouple provides compensation for transient temperature effects. The DC voltage generated between the hot and cold junction is proportioned to the pressure in the range of operation.

The Fredericks vacuum sensing probe Model 2100-32 is the thermocouple type consisting of a heater wire element and a thermocouple junction. The unit is housed in a stainless steel envelope with a standard 1/8-inch pipe thread connection on the stem. The readout meter is Fredericks Model No. 2A. A protective cap is placed over the miniature connector when the probe is not in use. The sensing element is a thermocouple junction welded to a nichrome heating element.

In operation, the heater element is maintained at an elevated temperature by passage of a constant current from the readout meter. The heater wire becomes hotter as the pressure decreases due to the reduced thermal conductivity of the gas in the system. This in turn results in a higher voltage being generated in the thermocouple circuit proportional to the system pressure in the operating range.

The Cryolab vacuum probe Model GT3-008-ST3 is a thermocouple type consisting of a dual element housed in a stainless steel envelope with a standard 1/8-inch pipe thread termination. A weather proof cap is furnished to protect the gold-plated pin connector when not in use. The Cryolab vacuum probe operates on the principle of the relationship of temperature to pressure due to the decreasing gas thermoconductivity as pressure is reduced. The Cryolab probe is novel in the fact that the thermocouple element is heated by an impressed R.F. signal from the supply source allowing two independent sensing elements to be installed in a single probe. The readout meter employed with the GT3-008-ST3 is Cryolab Model GT3-108.

5.2.2.3

Applicable Documents

The tests were conducted in accordance with the following documentation:

- A. KSC-STD-164D — "Environmental Test Methods for Ground Support Equipment Installations at Cape Kennedy"
- B. AMETEK/Straza Specification 8-480090 — "Design Verification Test Requirements — Vacuum Gauge Probes"

5.2.2.4 Tests Performed

5.2.2.4.1 Receiving Inspection

A. Test Requirements

A receiving inspection was performed to determine conformance of the vacuum probes with applicable drawings and specifications to the extent possible without disassembling the test units.

B. Test Procedure

Inspection data included the following:

- (1) Manufacturer, part number and serial numbers of each item.
- (2) Statement of condition of each item.
- (3) Dimension of each item.
- (4) Photograph and weight of one of each item of each part number.

C. Test Results

The receiving inspection showed the units to be in good condition with no scratches or marks on the body of the gauges. A preliminary helium leak test was performed on the units and one of the Fredericks probes, Serial No. 8, was found to leak through the pins in excess of 5.4×10^{-6} std cc/sec. This unit was returned to the Fredericks Company for replacement. The data sheets for the receiving inspection and photographs of the three types of vacuum probes tested are found on pages 50 through 52 and page 58.

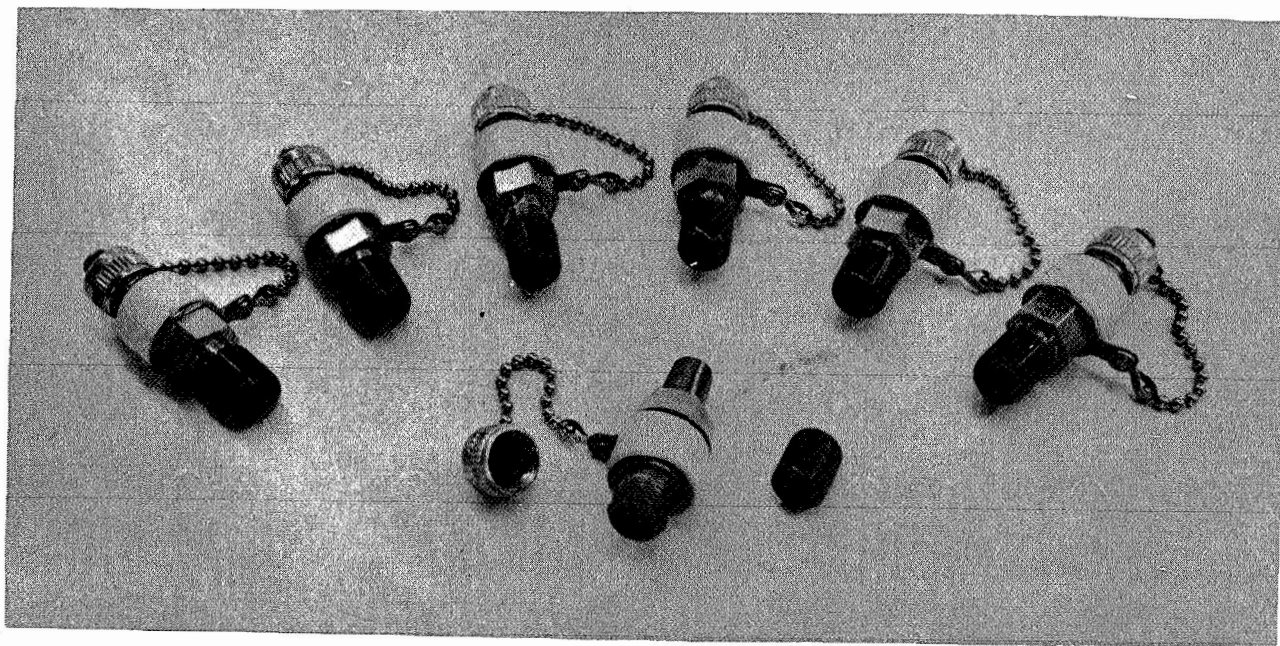


Figure 18.
Fredericks Vacuum Gauge Tubes

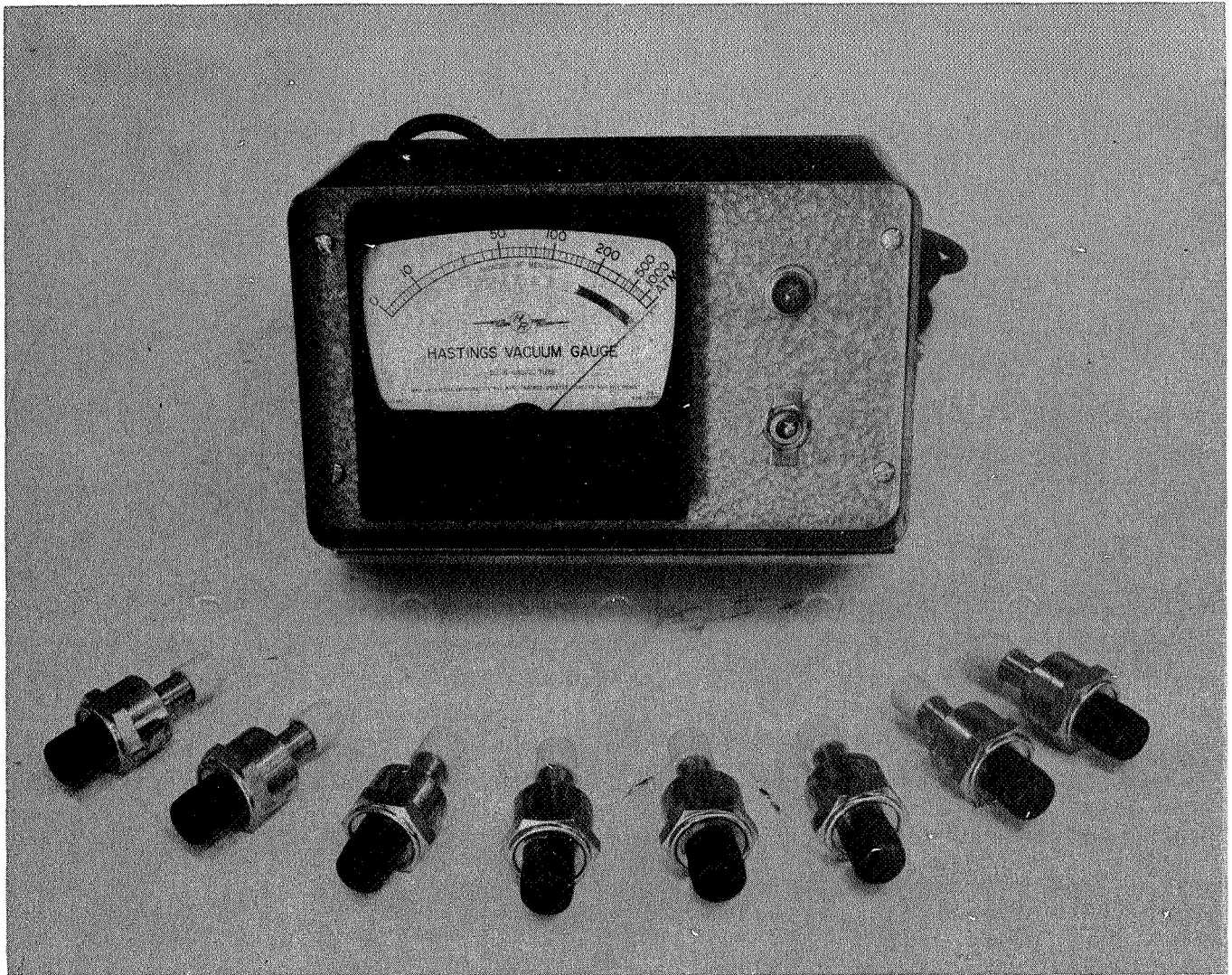


Figure 19.

Hasting Thermocouple Probe Test Specimen

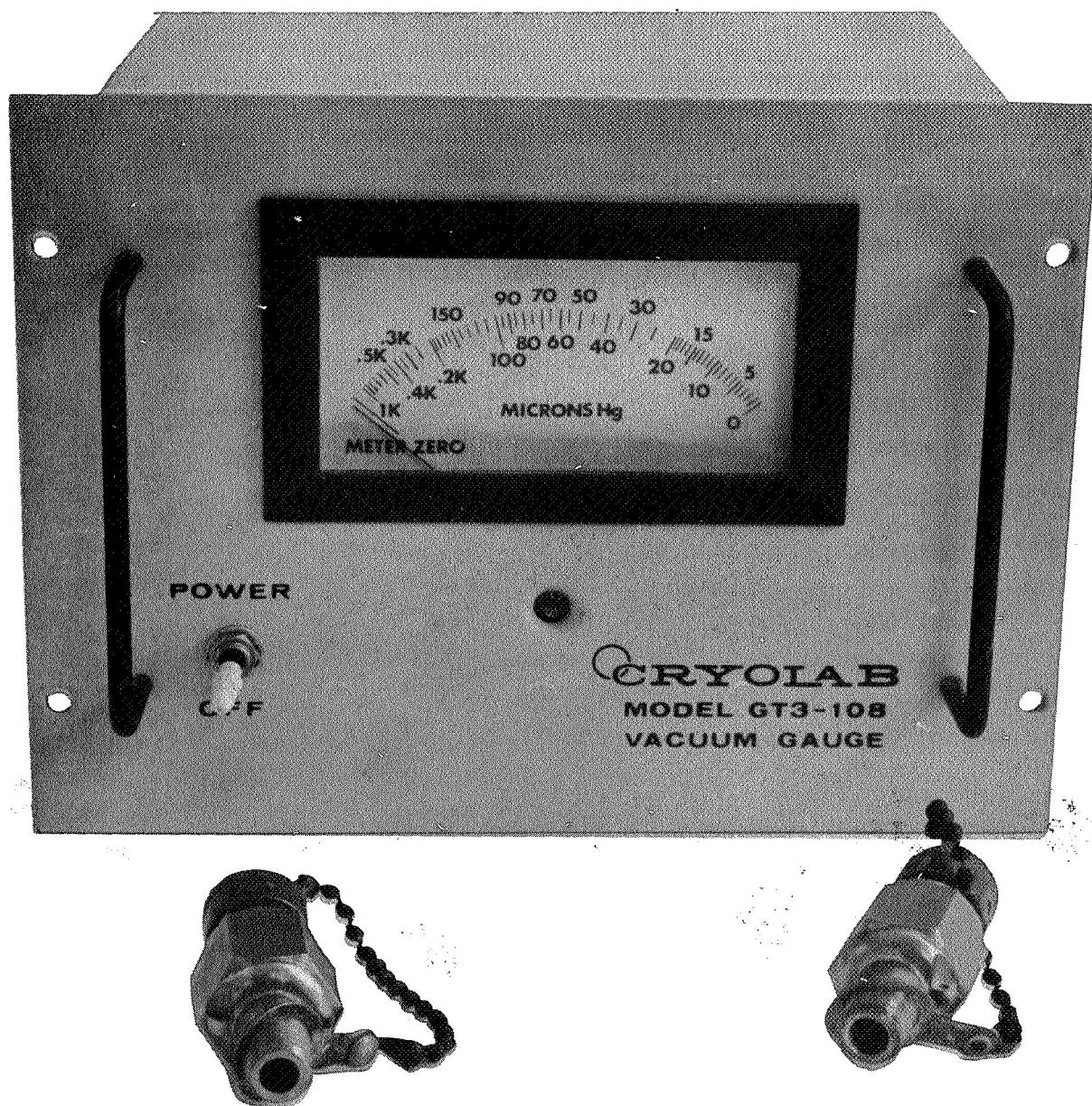


Figure 20.
Cryolab Vacuum Test Specimens With Readout Meter

5.2.2.4.2 Functional Test

A. Test Requirements

The test requirements were to mount the vacuum probes by their normal means and to determine that the vacuum probes would function within the parameters of the Task V Study Program specifications. Each vacuum probe was subjected to the following tests:

(1) Accuracy

Each vacuum probe was to be subjected to vacuum conditions of 1,000 microns, 500 microns, 200 microns, 100 microns, 50 microns, 20 microns, and 1 micron. Accuracy of the probes was to be within $\pm 10\%$ of full scale reading (1,000 microns) from 500 to 1,000 microns, within $\pm 10\%$ of the reading from 100 to 500 microns, and within ± 5 microns below 100 microns.

(2) Leakage

Leakage of the installed probes was to be measured with a helium mass spectrometer, with the leak rate not to exceed 1×10^{-7} std cc/sec of helium.

B. Test Procedure

Two test manifolds were fabricated out of stainless steel to accept the 24 test specimens. Each manifold held 12 specimens with four specimens of each manufacturer distributed randomly on the manifold. The method of mounting the probes was to wrap the 1/8-inch pipe threads of the specimens with teflon pipe tape, applying Silvac to the tape and screwing the probe into the manifold. Page 54 is a photograph of one manifold showing the distribution of the test specimens. After the units were installed, they were not removed or retorqued for the remainder of the test program.

- (1) The test manifold was connected to a vacuum source and a McLeod Gauge with a cold trap of LN₂ between the air admittance valve and McLeod Gauge and test manifold. See Page 55 for the Functional Test Setup.

The vacuum system was evacuated and allowed to stabilize at the test level of 1, 20, 50, 100, 500, and 1,000 microns.

Meter readings of the test specimens and of the McLeod Gauge were recorded at each level.

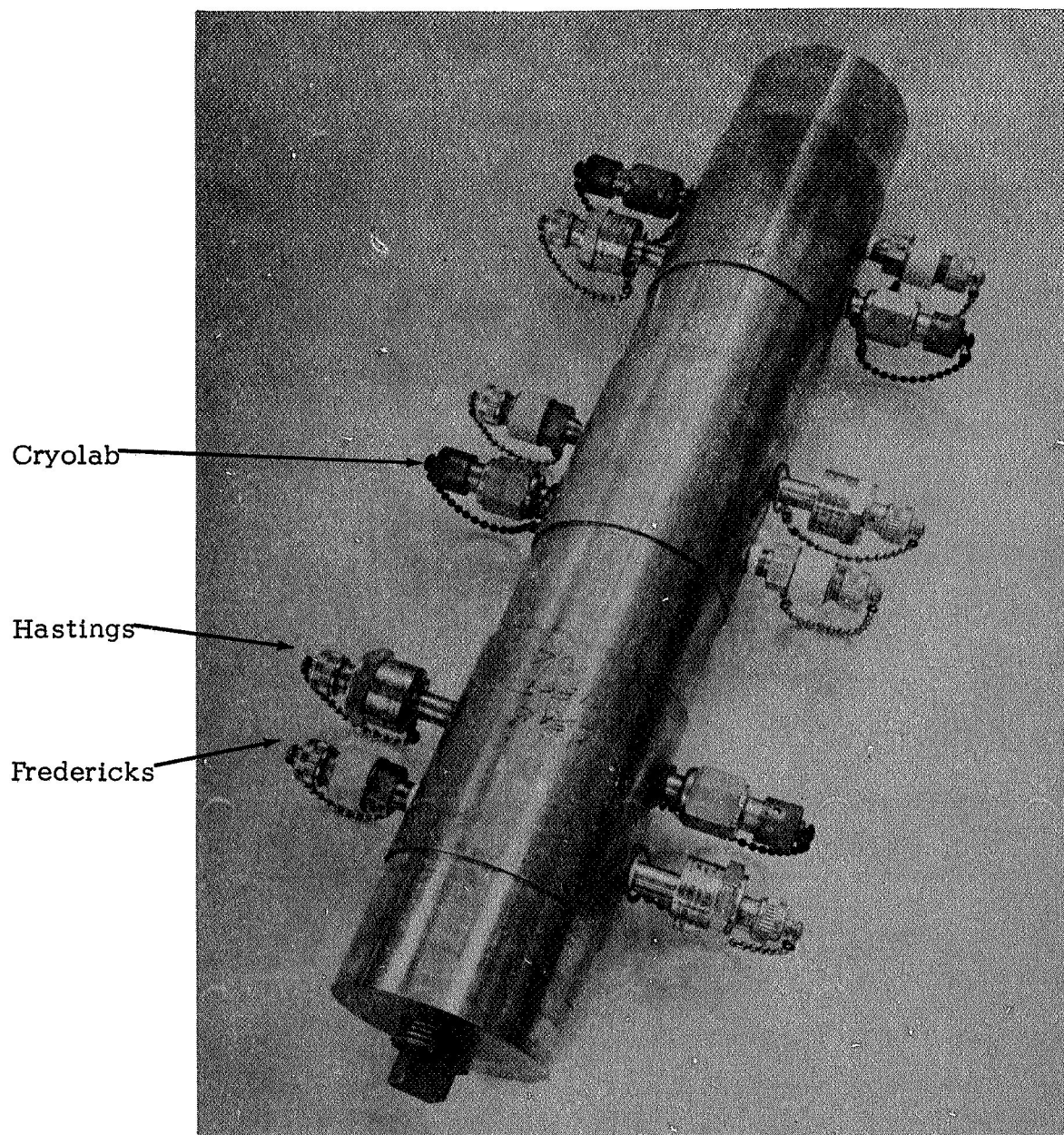


Figure 21.
Vacuum Probes Installed in Test Manifold
Note Random Placement of Probes in Test Manifold

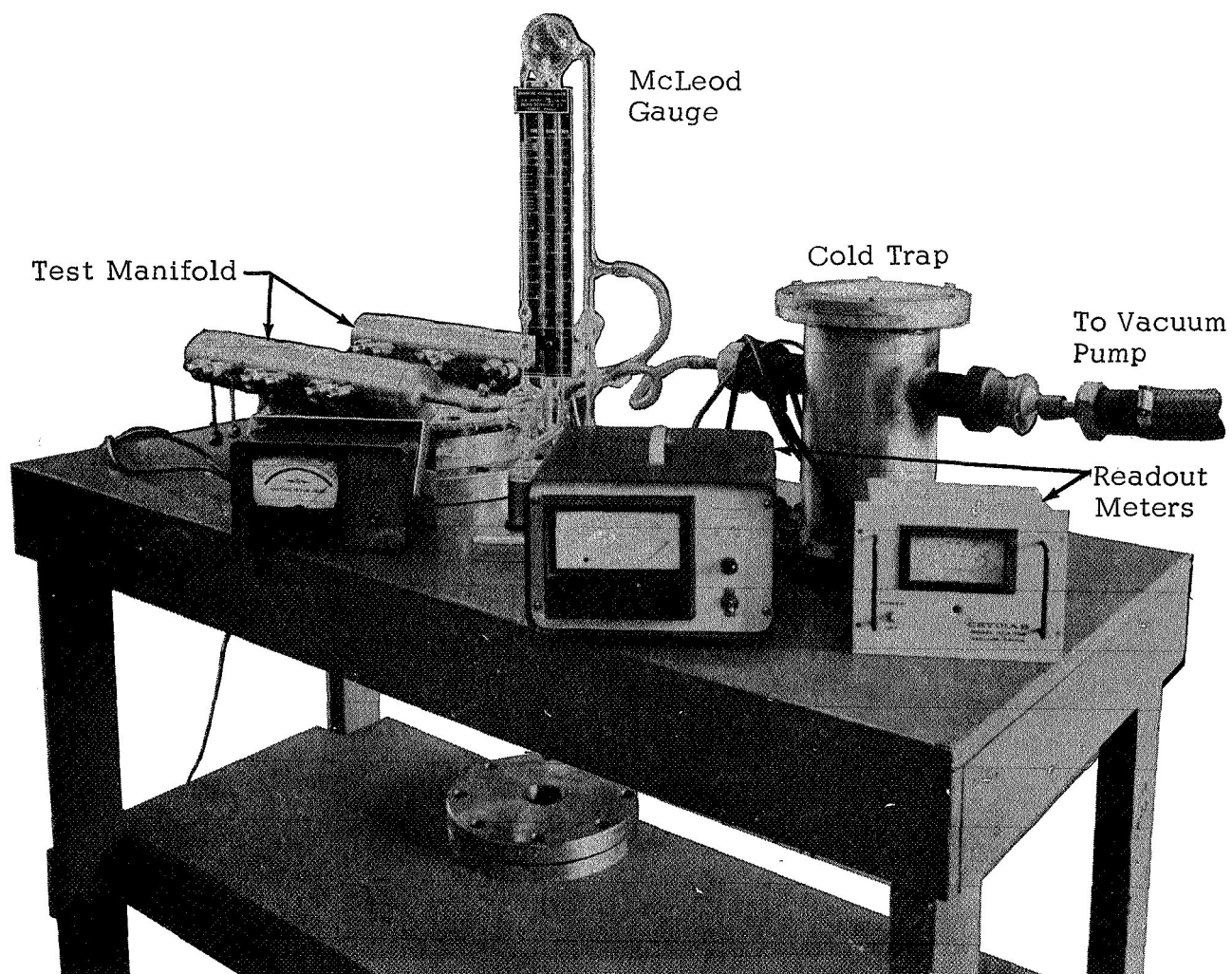


Figure 22.
Vacuum Probe Test Setup

(2) Leakage Test

The leakage test was performed employing a helium mass spectrometer. With the specimens remaining mounted, the test manifold tubes were connected to the mass spectrometer and evacuated to a level of 10 microns or better. Each specimen was sprayed with helium by means of a hypodermic syringe.

The leak rate was recorded for the manifold system and for an individual specimen if the leakage was out of specification.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

D. Test Results

(1) Accuracy

Initially only seven Fredericks specimens were tested due to the excessive leakage through the pins of specimen Serial No. 8. A replacement probe was received in time for the Sand and Dust Test. The Fredericks probes successfully passed the initial accuracy test. The meter was difficult to read above 500 microns and 1,000 microns.

The Cryolab vacuum probes failed to meet the accuracy specification at 100, 200, 500 and 1,000 microns. It was discovered that the readout meter had a faulty transistor, and the meter was replaced at the start of the Functional Test after Salt Fog.

The Hastings-Raydist vacuum probes met the accuracy requirements except for specimen No. 495 which had high output readings compared to the reference McLeod Gauge. The Hastings-Raydist Company was notified of the failure. They recommended a cleaning procedure instead of replacement. The unit was removed from the manifold and was carefully cleaned internally with acetone and dried. On retest the same results were obtained. Specimen No. 495 was used throughout the remaining tests.

Test results for the initial functional test are given in test data sheet found on Page 58.

(2) Leakage Test

The two manifolds were removed from the accuracy test setup and attached to the helium mass spectrometer. Leak rate of the total system was less than 1×10^{-10} std cc/sec of helium.

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician W. A. Bright

Date: 8/4/69

Test FIRST FUNCTIONAL

Standard		Microns													
		<1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
P/N GT3-008-5T3															
Serial Number H1		2	2	18	19	44	44	73	74	152	150	370	370	850	850
H2		4	4	22	22	51	49	89	86	175	168	425	390	1000	1000
H3		2.5	2.2	21	20	46	47	82	80	165	160	420	410	800	800
LEAK RATE ALL	H4	2.5	2	19.5	21	45	47	77	82	155	165	395	420	800	800
< 1 X 10 ⁻¹⁰	H5	3.2	.9	22	28	47	55	85	98	160	183	390	425	1000	1000
	H6	4.2	4.2	22	22	49	47	86	84	165	160	380	370	1000	1000
	H7	3.5	3	23	22	52	47	94	86	185	165	450	400	1000	1000
	H8	1.5	1	20.5	19	48	45	81	86	165	155	400	380	900	850
Fredericks															
P/N 2100-32															
Serial Number 1		1		18		50		98		145		500		1000	
2		1		18		49		97		192		500		1000	
LEAK RATE ALL	3	1		19		48		99		187		500		1000	
< 1 X 10 ⁻¹⁰	4	1		18		51		99		200		510		1000	
	5	1.2		19.5		48		98		190		490		1000	
	6	1		19		46		101		185		480		1000	
S/N 8 not installed.	7	1.8		19.5		47		99		185		480		1000	
	8	*													
Hastings															
P/N DV-36															
Serial Number 486		1.5		17		49		101		195		490		975	
495		28		41		72		122		210		670		1000	
LEAK RATE ALL	502	.5		17		47		94		195		490		975	
< 1 X 10 ⁻¹⁰	507	1.5		20		49		101		195		475		950	
	509	1		18		50		103		205		520		1000	
	511	2		17		51		105		205		510		1000	
	515	2.3		19		53		105		215		520		1000	
	520	1.3		19		50		100		210		520		1000	

5.2.2.4.3 Proof Pressure Test

A. Test Requirements

The test requirement was to proof pressurize each vacuum probe internally to 150 psig and afterwards to perform a functional test.

B. Test Procedure

The test manifolds with vacuum probe specimens were connected to a dry nitrogen gas source with a regulator and a pressure gauge for monitoring. The pressure was raised to 150 ± 3 psig and held for 2 minutes. The pressure was relieved and a functional test was performed as described in Paragraph 5.2.2.4.2.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Pressure Gauge	Helicoid	2284-0	A/S201	0-200 psig	$\pm 1/2\%$	Every 3 mos
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

D. Test Results

All specimens successfully passed the proof pressure test of 150 psig.

The data sheet for Functional Test is included on Page 61.

Cryolab test specimens H3 and H4 were slightly out of specification at 1 micron and Element B of Probe H5 was also out of specification. Meter readings from 100 to 1,000 microns for Cryolab specimens remained low. The meter was replaced after the salt fog test.

All Fredericks vacuum probes were within the specification.

All Hastings-Raydist vacuum probes were within specification except for specimen no. 495 which remained as in the initial functional test.

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician *W. J. Wright*

Date: 8/8/69

Test AFTER PROOF PRESSURE

Standard		Microns													
		< 1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
P/N GT3-008-5T3															
Serial Number	H1	2	3.5	17.5	19	45	46	90	83	155	155	375	350	750	750
	H2	3	2.2	20	17.5	49	45	83	83	180	155	410	380	750	750
LEAK RATE ALL	H3	5.5	5.5	20.5	20.5	49	49	83	82	170	170	410	400	800	800
<1 X 10 ⁻¹⁰	H4	5.5	5.5	20	21	47	50	79	85	165	175	380	410	800	800
	H5	1.2	9.8	17	25	46	54	82	93	155	175	350	400	700	850
	H6	2	1	18.5	16.5	49	44	91	82	175	160	400	400	950	800
	H7	5	5	20	20	47	47	78	78	160	160	390	390	750	750
	H8	4.8	4.5	21	20	49	48	85	80	175	160	410	380	800	750
Fredericks															
P/N 2100-32															
Serial Number	1	3		18		49		96		195		490		1000	
	2	2		18.5		48		100		190		475		1000	
LEAK RATE ALL	3	2.3		18.5		48		95		195		490		1000	
<1 X 10 ⁻¹⁰	4	4		20		51		95		200		500		1000	
	5	4		22.3		50		100		200		500		1000	
	6	4.5		21.5		51		100		198		480		1000	
*S/N 8 not installed.	7	5		22.3		50		100		197		480		1000	
Hastings	8	*													
P/N DV-36															
Serial Number	486	.8		16		48		101		190		475		950	
	495	31		43		78		118		225		510		1000	
LEAK RATE ALL	502	1.3		13		46		94		198		490		980	
<1 X 10 ⁻¹⁰	507	2.2		17		52		99		210		510		1000	
	509	1.5		15		47		98		198		495		950	
	511	.3		16		50		99		200		500		1000	
	515	1.3		18		51		100		210		520		1000	
	520	2		18		53		100		210		510		1000	

5.2.2.4.4 Salt Fog Test

A. Test Requirements

The test specimens were to be exposed to a salt fog atmosphere to determine their resistance to corrosion.

The specimens were to be exposed for 240 ± 2 hours in a salt fog of 5% salt and 95% water at $95 \pm 2/-4^{\circ}\text{F}$.

After the salt fog test the specimens were to be allowed to air dry and then inspected for corrosion, after which a functional test was to be performed.

B. Test Procedure

The test specimens still mounted on their manifolds and with their protective caps in place were placed in the salt spray chamber (see Pages 63 and 64).

The salt spray chamber was turned on and the specimens were maintained in a salt atmosphere for 240 hours at $95 \pm 2/-4^{\circ}\text{F}$.

At the end of the test period the units were visually inspected and a functional test was conducted.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Salt and Humidity Chamber	Bemco Inc.	SS-30	2211-1	---	---	---
Temperature Gauge (Potentiometer)	Leeds & Northrup	8693	1677669	$-340/+230^{\circ}\text{F}$		Every 3 mos
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Use

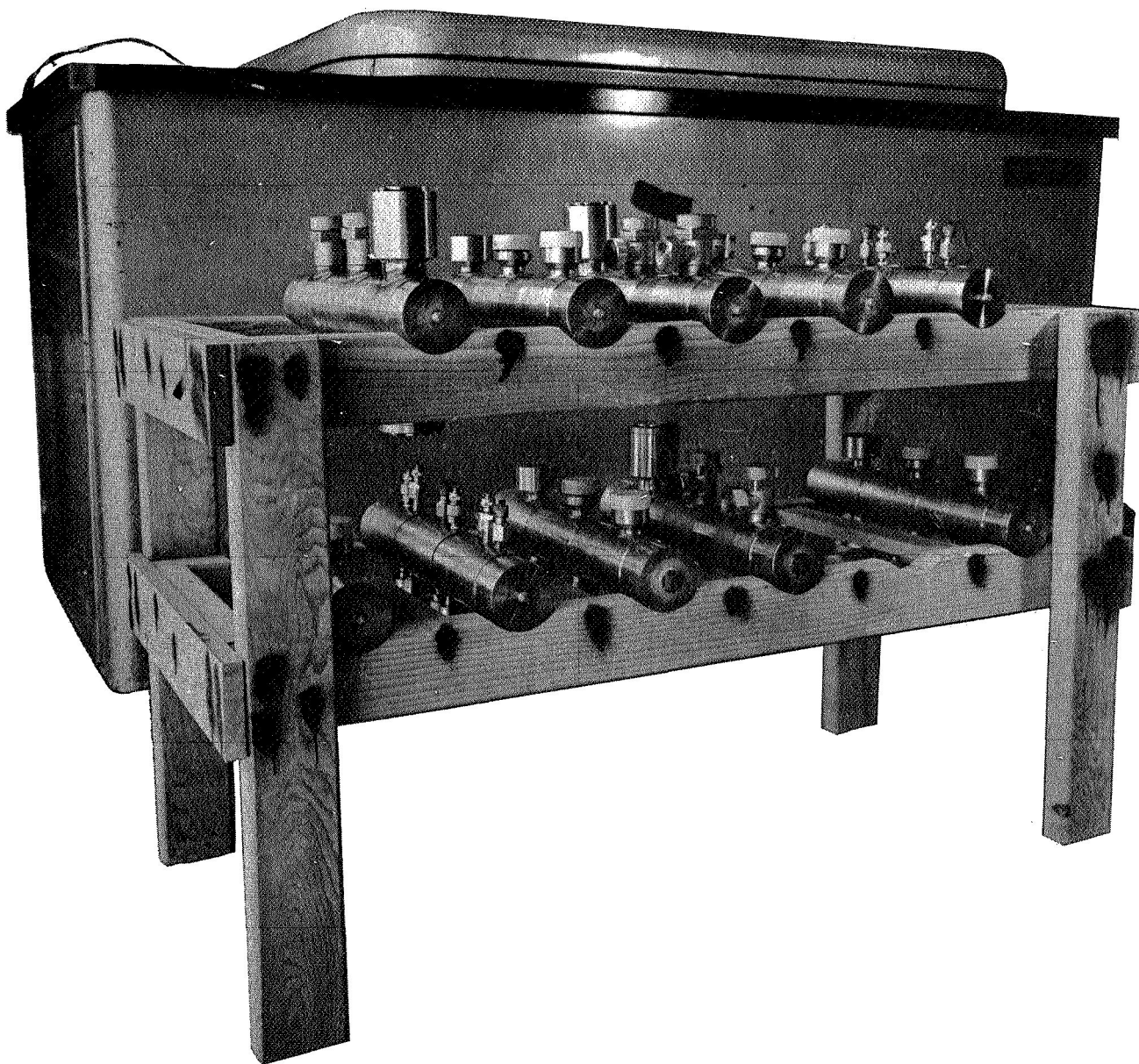


Figure 23.
Salt Fog Chamber and Test Manifold Support Rack

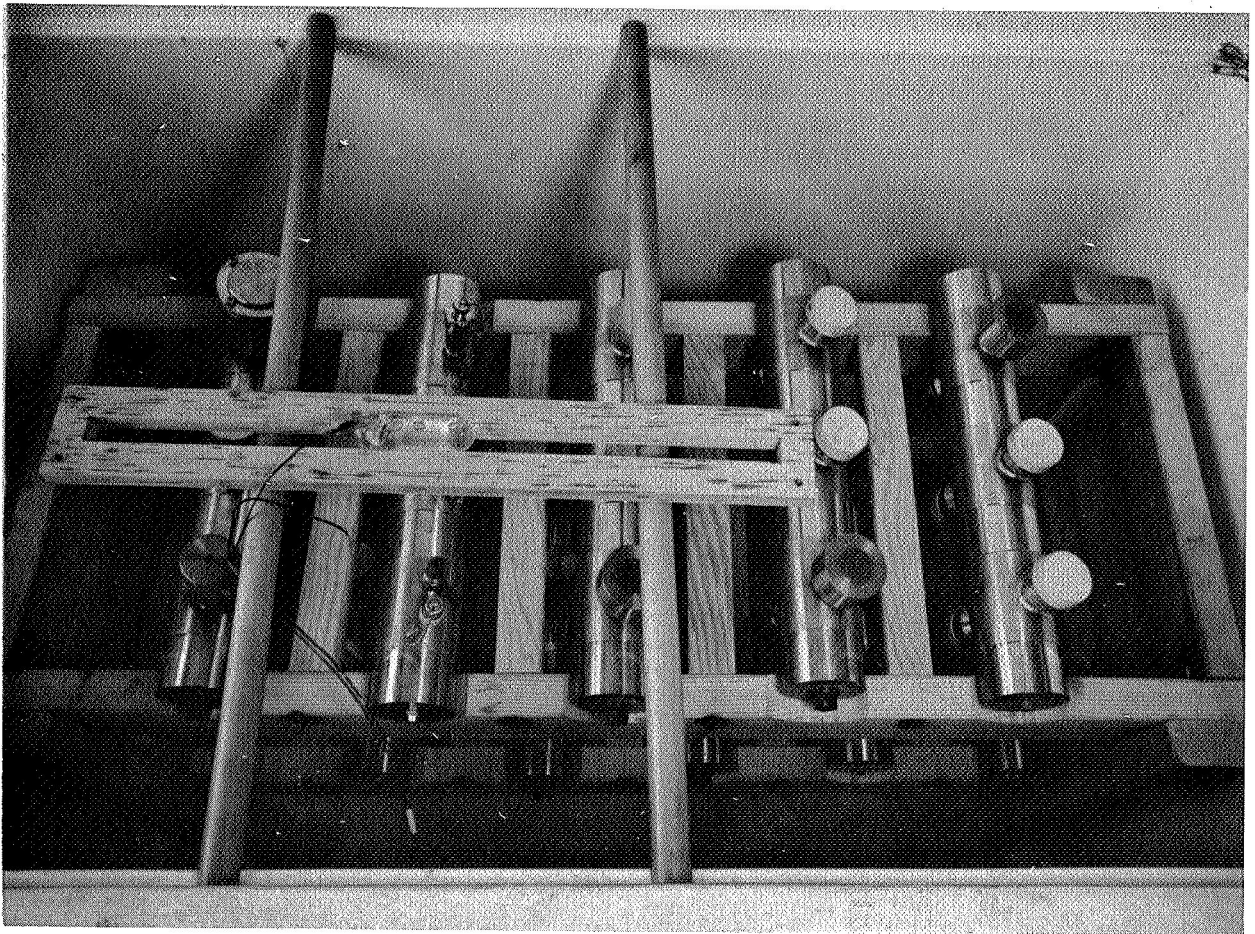


Figure 24.
Test Manifolds on Support Rack Inside Salt Fog Chamber
At Start of Salt Fog Test

C. Test Equipment (continued)

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Vacuum Pump	National Research Corporation	3305	2266-8820	1 x 10 ⁻⁶	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

D. Test Results

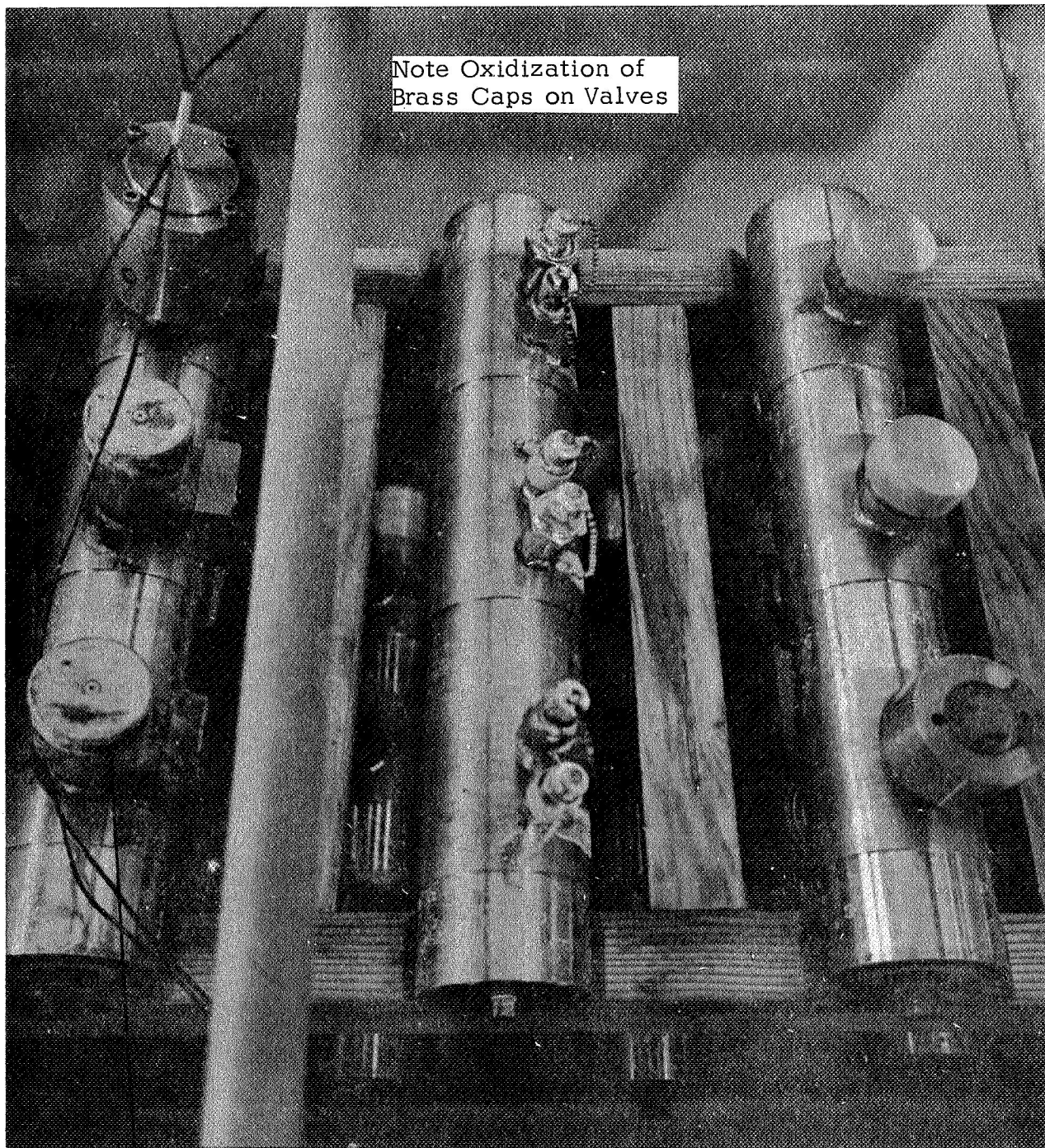
Examination of the test probes after salt fog revealed that at the sharp edges of the protective caps corrosion had taken place (see Page 66 and 67). Some corrosion was also observed where the metal chain attached to the protective cover. No damage was observed on the body or electrical connector. The covers were made of anodized aluminum.

The functional test was performed after the salt fog test. Cryolab had replaced the meter with the faulty electronics just prior to this test. Results showed in specification results at 100, 200, and 500 microns; however, low readings were obtained for the 1,000 micron range. The B element of H45 still remained out of specification at the lower range of 1, 20, 50, and at 1,000 microns.

All Fredericks vacuum probes remained within specification.

The Hastings-Raydist probe, Serial No. 495 remained out of specification. In addition, after the salt fog test, Serial No. 515 was also out of specification.

Although the test manifolds were cleaned for liquid oxygen service and the units were sealed from the atmosphere between tests, the change in readings of Cryolab H5, Element B, and Hastings-Raydist Serial No. 515 indicated some type of foreign substance on the sensing element. This, in part, could have been due to the continual release of vacuum to atmospheric pressure which would not normally occur under operating conditions at Cape Kennedy or other vacuum systems which operate on a continuous static vacuum. See tabulated test results on Pages 68 and 69.



Note 304 Stainless
Steel Port Cap Corrosion

Note Drainage From
Vacuum Probe Caps

Figure 25.
Vacuum Seal Valves, Vacuum Probes, And
Burst Discs Following Salt Fog Test

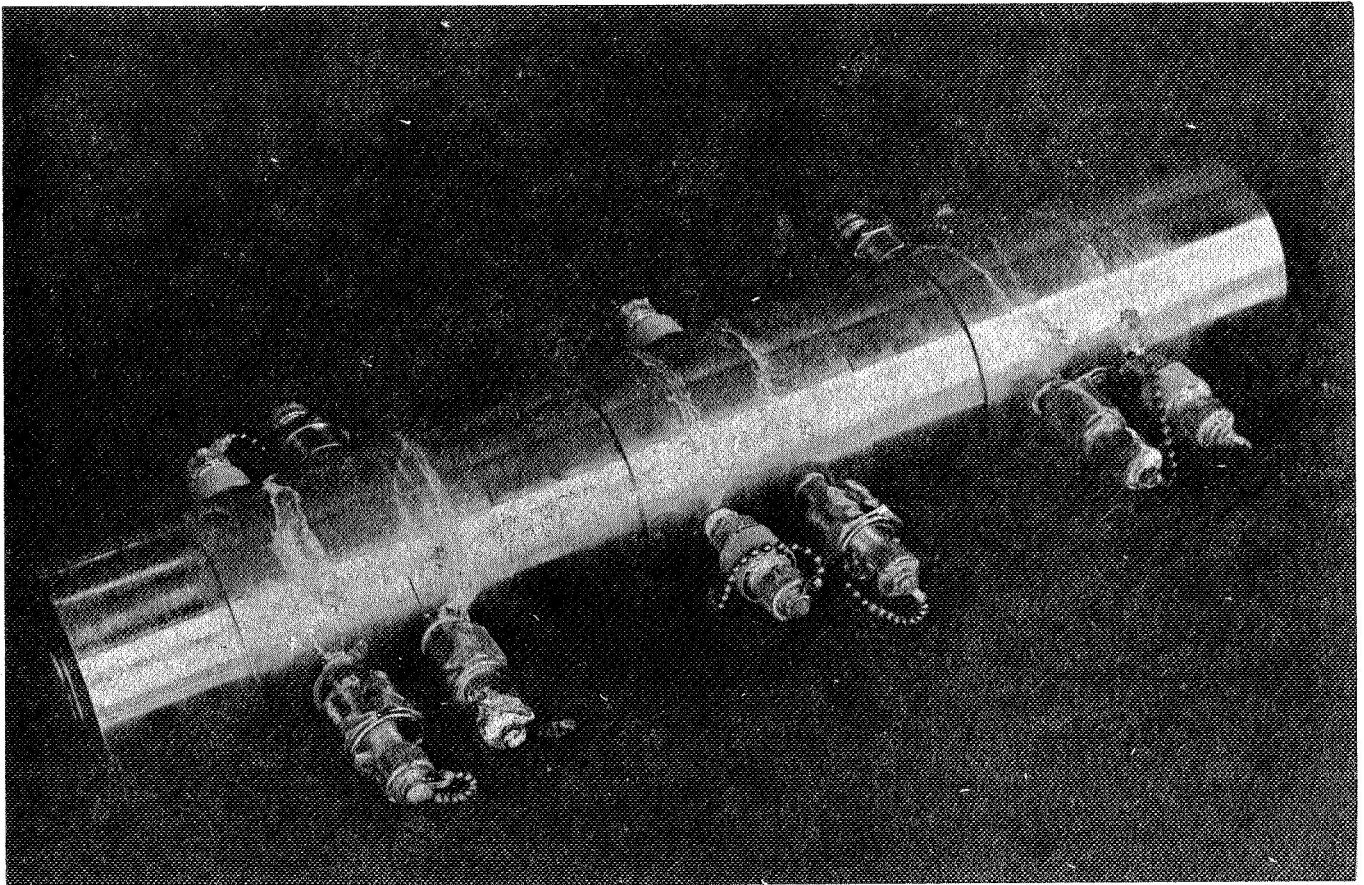


Figure 26.
Vacuum Probe Specimen After Salt Fog Test

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test SALT FOG Date of Test 12 August to 22 August

Part Name Vacuum Gauge Probes Part Number Cryolab - G+3-008-5+3

Test Procedure 8-480090 Part Serial Number Hastings - DU36

Test Pressure 8-480090 Part Serial Number Fredericks - 2100-32

Test Pressure _____ Test Media _____ Duration of Test 244 hrs.

<u>Manufacturer</u>	<u>Serial Number</u>	<u>Remarks</u>
1. <u>Fredericks</u>	<u>-</u>	<u>Severe corrosion on protective cover</u>
2. <u>Hastings</u>	<u>520</u>	<u>Severe corrosion on protective cover</u>
3. <u>Cryolab</u>	<u>H7</u>	<u>Leaked thru body 5 x 10⁻⁶</u>
4. <u>Hastings</u>	<u>502</u>	<u>Severe corrosion on protective cover</u>
5. <u>Fredericks</u>	<u>5</u>	<u>Severe corrosion on protective cover</u>
6. <u>Cryolab</u>	<u>H8</u>	<u>Some corrosion on protective cover chain</u>
7. <u>Cryolab</u>	<u>H3</u>	<u>Some corrosion on protective cover chain</u>
8. <u>Hastings</u>	<u>495</u>	<u>Corrosion on protective cover</u>
9. <u>Fredericks</u>	<u>6</u>	<u>Corrosion on protective cover</u>
10. <u>Cryolab</u>	<u>H4</u>	<u>Corrosion on chain</u>
11. <u>Hastings</u>	<u>509</u>	<u>Corrosion on protective cover</u>
12. <u>Fredericks</u>	<u>7</u>	<u>Corrosion on protective cover</u>
13. <u>Cryolab</u>	<u>H1</u>	<u>Corrosion on chain</u>
14. <u>Hastings</u>	<u>515</u>	<u>Corrosion on protective cover</u>
15. <u>Fredericks</u>	<u>4</u>	<u>Corrosion on protective cover</u>
16. <u>Cryolab</u>	<u>H2</u>	<u>Corrosion on chain & protective cover</u>
17. <u>Hastings</u>	<u>486</u>	<u>Corrosion on protective cover</u>
18. <u>Fredericks</u>	<u>2</u>	<u>Corrosion on protective cover</u>
19. <u>Fredericks</u>	<u>3</u>	<u>Corrosion on protective cover</u>
20. <u>Cryolab</u>	<u>H5</u>	<u>Corrosion on protective cover & chain</u>
21. <u>Hastings</u>	<u>511</u>	<u>Corrosion on protective cover</u>
22. <u>Fredericks</u>	<u>1</u>	<u>Corrosion on protective cover</u>
23. <u>Cryolab</u>	<u>H5</u>	<u>Corrosion on protective cover & chain</u>
24. <u>Hastings</u>	<u>507</u>	<u>Corrosion on protective cover</u>

Test Technician *ma Bright*

Test Engineer _____

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician Smith

Date: 8/26/69

Test AFTER SALT FOG

Standard		Microns													
		< 1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
P/N GT3-008-ST3															
Serial Number H1		1.2	2.5	222	24	49	50	103	103	195	190	550	520	800	800
H2		4	2	22	18	54	49	111	102	220	195	600	550	850	800
S/N 7-LEAK RATE															
> 5 X 10 ⁻⁶ . THRU															
BODY. REPAIRED															
WITH SILVAC SEAL															
ANT. LEAK RATE															
ON ALL OTHER															
UNITS < 1 X 10 ⁻¹⁰															
H3		2	2	23	22	52	51	103	100	210	200	600	570	850	800
H4		1.5	1.7	20.5	22	49	53	99	105	195	210	550	600	800	850
H5		1.5	10	18	27	49	59	102	115	190	220	600	550	800	850
H6		2	1.5	20	17.5	52	48	110	103	220	190	600	570	900	800
H7		2	2	17.5	17.2	50	50	100	100	190	190	550	550	800	800
H8		2	1.7	21.7	20.2	53	51	107	100	210	185	590	510	850	800
Fredericks															
P/N 2100-32															
Serial Number 1		2		18		49		99		190		600		1000	
2		1.7		17		47		99		190		550		1000	
LEAK RATE ALL															
3		1		17		48		99		190		500		1000	
< 1 X 10 ⁻¹⁰															
4		3		18		49		100		200		600		1000	
5		< 1		19.5		48		96		190		600		1000	
6		< 1		19		47		95		190		550		1000	
S/N 8 not															
installed.															
7		< 1		19		47		95		190		550		1000	
8		*													
Hastings															
P/N DV-36															
Serial Number 486		1.5		16		47		103		200		520		900	
495		22		41		67		117		200		520		950	
502		1		18		47		100		195		500		920	
LEAK RATE ALL															
507		1.2		16		47		103		195		500		9900	
< 1 X 10 ⁻¹⁰															
509		1.2		20		50		106		210		570		1000	
511		1.0		17		49		110		210		600		1000	
515		30		50		84		132		390		1000		> ATM	
520		2		21		50		108		210		600		1000	

5.2.2.4.5 Sand and Dust Test

A. Test Requirements

The Sand and Dust test required that the vacuum probes be placed in a test chamber and be exposed to a sand and dust environment with a sand to dust ratio of 0.1 to 0.25 grams per cubic foot and with an air velocity of from 100 to 500 feet per minute.

The air temperature was to be maintained at $77 \pm 2^\circ\text{F}$ for 2 hours and then raised to $160 \pm 2^\circ\text{F}$ for an additional 2 hours.

At the conclusion of the sand and dust test, the vacuum probes were to be visually inspected and then a functional test performed.

B. Test Procedure

The Sand and Dust tests were performed at Ogden Technology Laboratories located at Monterey Park, California (see Test Summary Sheet, Page 72).

The specimens with the protective covers in place and mounted in the test manifolds were placed vertically in the sand and dust chamber for a total of 4 hours.

C. Test Equipment

See Sand and Dust data sheet (Page 72) from Ogden Technology.

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibratio
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Us
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Us
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mo
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mo

D. Test Results

Ogden Technology test data sheet (Page 72) reflects the Sand and Dust test data. No visible damage was noted as the result of the Sand and Dust tests.

Results of the functional test after the Sand and Dust test (Page 73) showed one out of specification reading for Fredericks vacuum probe Serial No. 4 at 50 microns. All other Fredericks probes were within specification.

Hastings-Raydist vacuum probe, Serial No. 495 remained out of specification at the lower micron readings while Serial No. 515 had failed completely electrically. The remaining Hastings-Raydist probes all displayed low readings at 20 microns, being out of specification by 1 or 2 microns.

Cryolab vacuum probes, Serial No. H1, Element A, and Serial No. H5, Element B continued to have high out of specification readings at the lower end of the scale. Readings remained low at 1,000 microns.

SAND AND DUST DATA SHEET

Date 8-29-69 Job Number M69477
 Customer AMETEK/Straza Page Number _____
 Specimen Vacuum Probes Part No. _____ Serial No. As Noted
 Specification No. 8-480090 Para. No. _____
 Preparation of Specimen(s) 2 Tube Assemblies

Protective Covering on Non-Tested Parts Capped

Vents, Ports, Connectors, etc., Capped: Yes X No _____ Remarks _____

Support Method _____

Orientation of Specimen(s) Vertically Supported

Chamber Controls: Sand and Dust Density 0.1 to 0.25 grams/cubic foot

Wind Velocity 100 to 500 feet/minute

Relative Humidity 30% percent

Temperature 77 °F

Elapsed Time (hours)	Sand and Dust Density (grams/cu.ft.)	Air Velocity (ft/minute)	Temperature (°F)	Relative Humidity (%)
<u>1020</u>	<u>0.25</u>	<u>375</u>	<u>76</u>	<u><30</u>
<u>1120*</u>	<u>0.25</u>	<u>375</u>	<u>78</u>	
<u>1630</u>	<u>0.25</u>	<u>375</u>	<u>78</u>	<u><30</u>
<u>1730*</u>	<u>0.25</u>	<u>375</u>	<u>78</u>	
<u>1210 9-2-69</u>	<u>0.25</u>	<u>375</u>	<u>158</u>	<u><30</u>
<u>1410</u>	<u>0.25</u>	<u>375</u>	<u>159</u>	

Remarks: _____

Interruptions during test (Explain): Test stopped to cycle valves and disassemble burst discs

Results: Damage or Deformation: Yes _____ No X (Explain above) _____

Photograph taken: Yes X No _____

Test Technician _____ Test Engineer _____

Inspector (Customer or U.S. Gov't). _____

Q.A. Mgr. Signature _____

Report Number M-69477

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician ma Bright

Date: 9/4/69

Test AFTER SAND AND DUST

Standard		Microns													
		<1		20		50		100		200		500		1000	
Cryolab		A	B	A	B	A	B	A	B	A	B	A	B	A	B
P/N GT3-008-5T3															
LEAK RATE ALL <1 x 10 ⁻¹⁰	Serial Number H1	31	4	50	19	76	45	125	90	230	195	550	500	900	800
	H2	3	1	19	17	49	43	98	89	200	195	550	500	900	800
	H3	1	1.5	17	17	45	44	92	90	200	195	550	525	900	800
	H4	1	1	14.5	17	41	46	85	95	190	200	500	550	800	925
	H5	1	9	16	25	44	52	89	100	180	190	500	550	800	950
	H6	<1	<1	16.5	17	46	44	98	90	200	195	600	525	900	800
	H7	1	1.5	16	16	42	42	90	86	195	180	500	500	800	850
	H8	.5	1	17	16	54	44	95	89	200	195	550	500	900	800
Fredericks P/N 2100-32															
LEAK RATE ALL <1 x 10 ⁻¹⁰	Serial Number 1	3		21		49		95		215		550		1000	
	2	2		20.5		47		98		210		600		1000	
	3	2		20		45		96		210		600		1000	
	4	3		23		52		105		220		600		1000	
	5	3		21		46		90		220		550		1000	
	6	3		20		45		90		210		500		1000	
	7	2		23		45		90		200		500		1000	
	8	<1		19		41		90		220		600		1000	
Hastings P/N DV-36															
LEAK RATE ALL <1 x 10 ⁻¹⁰	Serial Number 486	1		13		40		90		198		490		1000	
	495	23		41		70		115		200		500		1000	
	502	<1		12		40		88		195		500		950	
	507	<1		13		40		90		198		500		950	
	509	<1		13		41		95		210		500		1000	
	511	<1		14		42		95		200		500		1000	
	515	ATM		ATM		ATM		ATM		ATM		ATM		ATM	
	520	1		14		43		90		210		600		1000	

5.2.2.4.6 Low Temperature Test

A. Test Requirement

The Low Temperature test was conducted to determine the resistance of the vacuum probes to a temperature of $-65 \pm 0/-4^{\circ}\text{F}$.

B. Test Procedure

The test specimens with the protective covers in place were installed in the low temperature chamber.

A thermocouple was attached to the body of the test manifold and the temperature reduced at a rate of 1° per minute.

At -65°F the test specimen was allowed to stabilize, at which time the test chamber was turned off and the test specimens were allowed to return to room ambient temperature.

A functional test was then performed on the vacuum probes.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Low Temperature Chamber	Sub-Zero Products	V-120	55371	Ambient	$\pm 1^{\circ}\text{F}$	---
Potentiometer Gauge	Leeds & Northrup	8693	1677669	$-340^{\circ}/+230^{\circ}$	---	Every 3 mos
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

D. Test Results

Hastings-Raydist vacuum probes, Serial No. 495 remained out of specification at 1, 20, and 50 microns while Serial No. 515 remained inoperative.

All Fredericks vacuum probes were within specification.

Cryolab vacuum probe, Serial No. H1, Element A remained out of specification at the test levels to 200 microns.

Leakage of all units remained at less than 1×10^{-7} std cc/sec of helium.

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician *Amcwright*

Date: 9/11/69

Test AFTER LOW TEMPERATURE

Standard		Microns													
		< 1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
P/N GT3-008-5T3															
Serial Number	H1	33	6	52	21	80	48	125	94	225	190	510	500	800	750
	H2	4	2	21	18	50	45	100	92	200	192	550	500	900	800
LEAK RATE ALL	H3	2	2	20	19	46	44	96	95	195	195	550	520	800	800
<1 X 10 ⁻¹⁰	H4	1	1	20	20	42	46	90	100	175	200	500	550	800	800
	H5	2	10	17	25	46	55	90	102	190	210	500	525	800	900
	H6	2	2	18	17	49	46	100	92	210	195	500	575	900	800
	H7	1.5	2	18	18	44	43	90	90	195	190	500	500	800	850
	H8	1.5	1	20	18	47	44	100	92	200	200	550	500	800	750
Fredericks															
P/N 2100-32															
Serial Number	1	3		20		49		97		215		600		1000	
	2	2		19		49		100		205		600		1000	
LEAK RATE ALL	3	2		19		49		95		205		600		1000	
<1 X 10 ⁻¹⁰	4	3.5		21		52		105		220		600		1000	
	5	< 1		19		46		97		215		600		1000	
	6	1		19		45		96		195		600		1000	
	7	1		20		45		95		195		600		1000	
	8	1		19		47		95		195		550		1000	
Hastings															
P/N DV-36															
Serial Number	486	1		15		42		105		195		500		950	
	495	20		38		60		110		200		500		950	
LEAK RATE ALL	502	2		15		41		95		210		500		950	
<1 X 10 ⁻¹⁰	507	1		14		43		93		195		500		950	
	509	< 1		17		42		100		200		600		1000	
	511	1		15		46		99		205		550		1000	
	515	ATM		ATM		ATM		ATM		ATM		ATM		ATM	
	520	< 1		16		44		100		210		600		1000	

5.2.2.4.7 High Temperature Test

A. Test Requirements

The High Temperature test was conducted to evaluate the test specimens under the most severe high temperature condition to be encountered, that of its proximity to the blast of a launch vehicle during lift-off.

The test specimens were to be exposed to a flame temperature of $1400 \pm 100^{\circ}\text{F}$ for a period of 10 seconds.

B. Test Procedure

As shown in the photograph of the test setup (see Page 79), the test specimens were mounted in a fixed position.

The flame temperature was determined with a thermocouple and a potentiometer. Three specimens of each type were then exposed to the $1400 \pm 100^{\circ}\text{F}$ temperature for a period of 10 seconds. After the high temperature test, a functional test was performed.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	$\pm 10\%$	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

D. Test Results

Only one unit of each type was tested because under normal installation a protective container is screwed in place over the vacuum probe. All units were operational after the high temperature test. The plastic bumper furnished on the Fredericks vacuum probe as requested had charred (see photograph on Page 80). The functional test after the high temperature test showed that the Cryolab Vacuum probe, Serial No. H1, which had the A element out of specification prior to the high temperature was now within specification.

The Fredericks vacuum probe, Serial No. 4, was out of specification for all test levels.

The Hastings-Raydist vacuum probe H495 selected because of its out of specification readings from previous tests showed little effect from the high temperature test.

During the leakage test, Cryolab vacuum probe, Serial No. H4, which was not exposed to the severe high heat, but was located 4.5 inches from the flame source, had a leak rate of 4×10^{-6} std cc/sec of helium gas. The leak was determined to be at the silver solder junction between the electrical connector and the body of the vacuum probe. The leak was repaired with Silvac and continued in the test program.

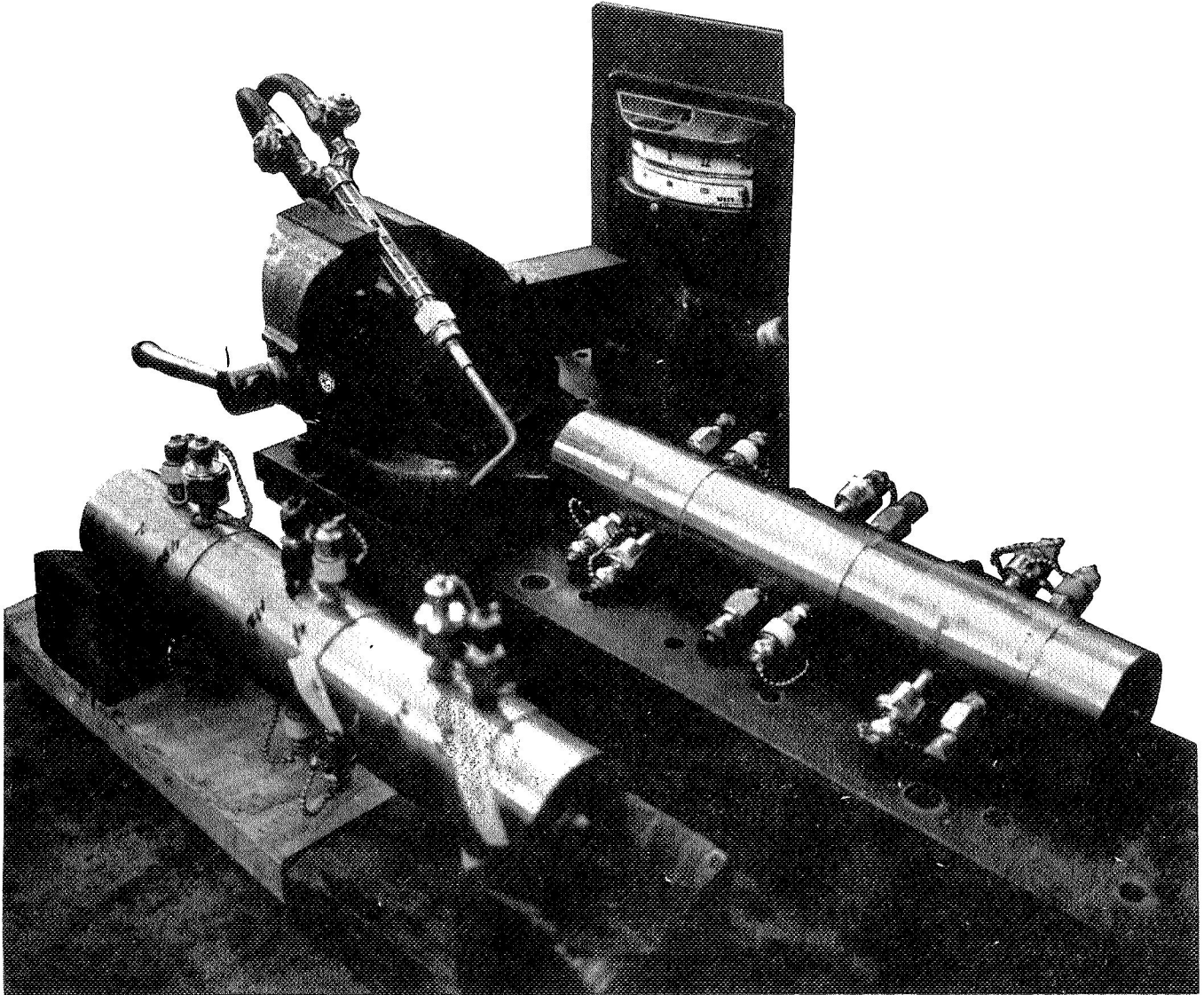


Figure 27.
High Temperature Test Setup for the Thermocouple Probes

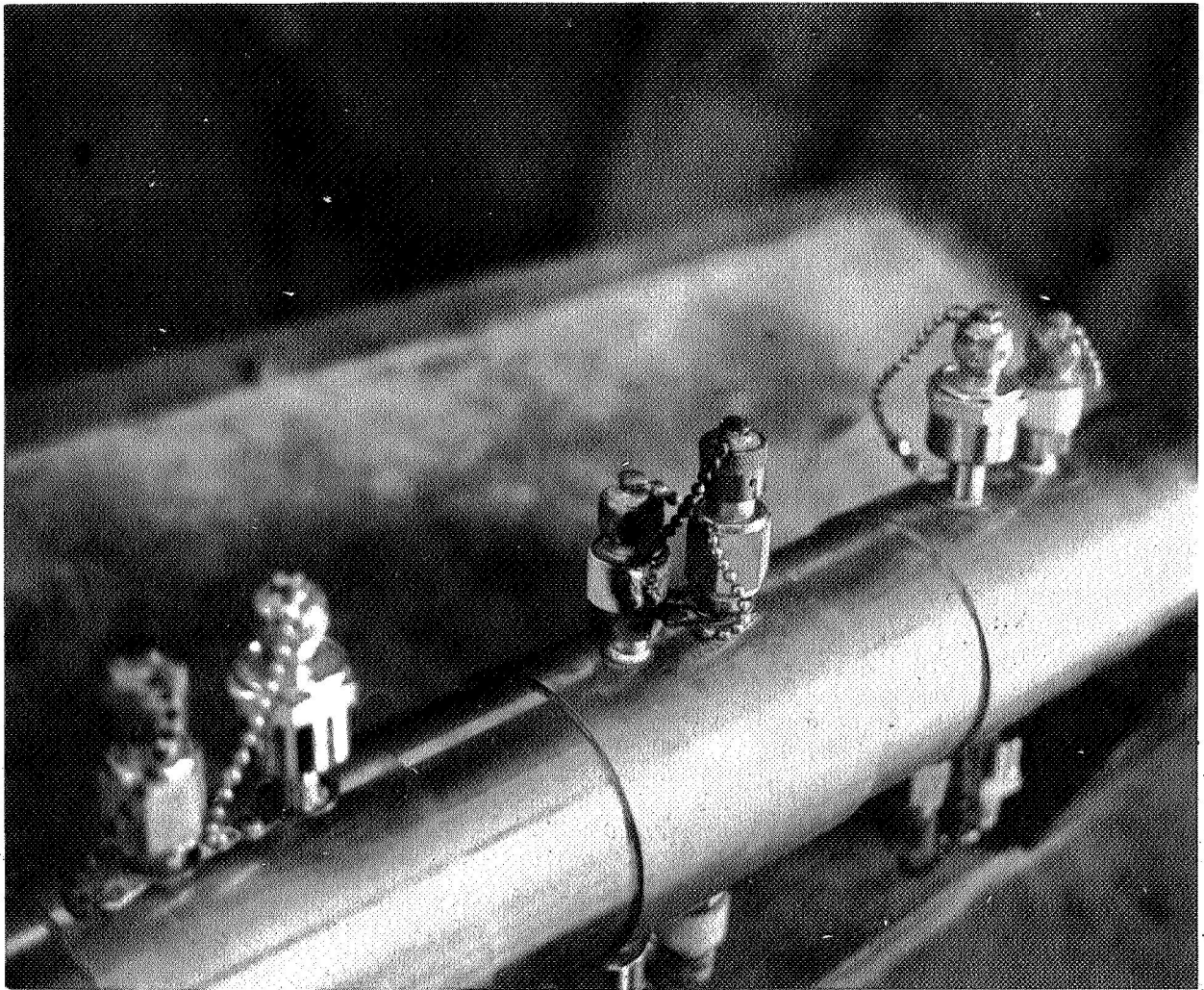


Figure 28.
Result of Heat on the Bumper Guard on the Fredericks T.T. Gauge

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician McBride

Date: 9-18-69

Test After High Temperature

Standard		Microns													
		<1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
P/N GT3-008-5T3															
Serial Number	H1	2	5	16.5	15	45	46	93	95	195	198	500	495	800	850
	H2														
LEAK RATE	H3														
<1 x 10 ⁻¹⁰	H4														
	H5														
	H6														
	H7														
	H8														
Fredericks															
P/N 2100-32															
Serial Number	1														
	2														
LEAK RATE	3														
<1 x 10 ⁻¹⁰	4	9		26		57		120		250		800		1000	
	5														
	6														
	7														
	8														
Hastings															
P/N DV-36															
Serial Number	486														
	495	20		34		58		100		200		500		990	
LEAK RATE	502														
<1 x 10 ⁻¹⁰	507														
	509														
	511														
	515														
	520														

5.2.2.4.8 Vibration Test

A. Test Requirements

The vibration test was to be performed to determine the vacuum probe's integrity in the predicted vibration environment.

B. Test Procedure

The vibration fixture with a dummy test manifold was installed on the vibration excitor and checked for resonant frequency and crosstalk. The dummy manifold was removed and the test manifold was installed in the vibration fixture. Photographs on Pages 84, 85, and 86 show the test setup in the X, Y, and Z axes.

The test manifold was connected to the helium mass spectrometer and evacuated.

One of each type vacuum probe was connected to the vacuum probe readout meter. The test manifold was covered with a polyethylene bag and filled with helium. A resonant search was conducted in the X-axis. After the resonant search, a resonant sweep was made in the X axis as required.

Due to schedule limitations, the random vibration tests were not conducted. Upon completion of vibration testing in the X-axis, the same cycle was repeated in the Y and Z axes.

During vibration the units were monitored for leakage and checked for electrical continuity. At the completion of the vibration tests a functional test was performed.

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Oscillator Servo-Cycling	Bruel & Kjoer	1018	80029	5Hz/10KHz	$\pm 0.25\text{Hz}/1\%$	Prior to Use
Power Amplifier	Ling	CP10/ 16AVC	61	5-3000Hz	---	---
Shaker	Ling	B-300	68	5-3000Hz	---	---
Accelerometer	Endevco	2242C	FA44	5-6000Hz	$\pm 5\%$	Prior to Use
Accelerometer	Endevco	2242C	Fa79	5-6000Hz	$\pm 5\%$	Prior to Use

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Accelerometer	Endevco	2242C	HB21	5-6000Hz	±5%	Prior to Use
Accelerometer	Endevco	2242C	FA75	5-6000Hz	±5%	Prior to Use
Accelerometer Amplifier	Unholtz-Dickie	603R	165	10-5000Hz	±2%	Prior to Use
Dynamic Analyzer	Spectral Dynamics	SD101A	330	2Hz/25Hz	±0.25db	Prior to Use
Vacuum Tube Voltmeter	Hewlett-Packard	400D	001-34343	10cps	±2%	3 month interval
Electronic Counter	Hewlett-Packard	521C	2427	1Hz/ 120KHz	±1 count ±0.01%	6 month Interval
Oscillographic Recorder	Sanborn	350	477	5Hz/ 100KHz	±1mm	Prior to Use
Mass Spectrometer Vacuum	CEC	24-120A	7104	5.4×10^{-6} 1×10^{-10}	±10%	Prior to Use
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	±10%	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

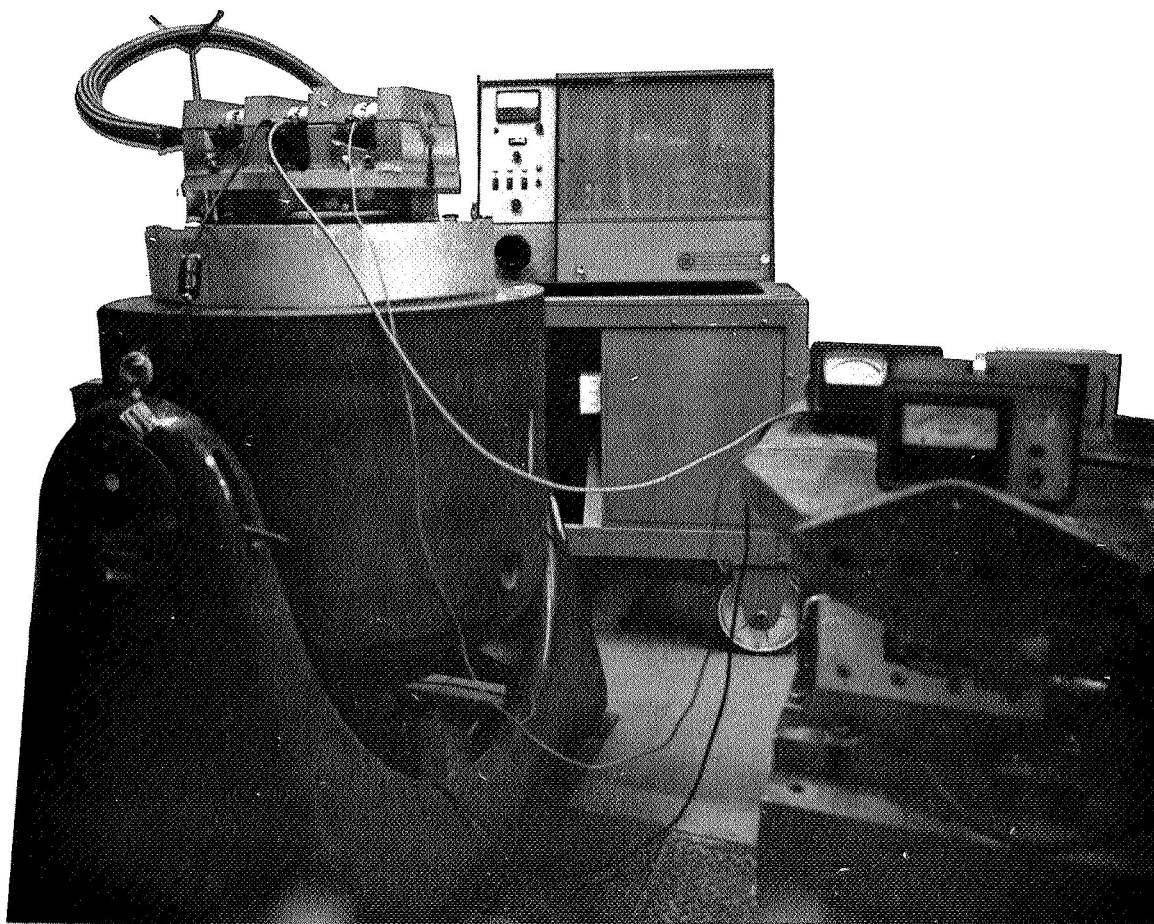


Figure 29.
Vibration Test of Vacuum Probes in the X-Axis

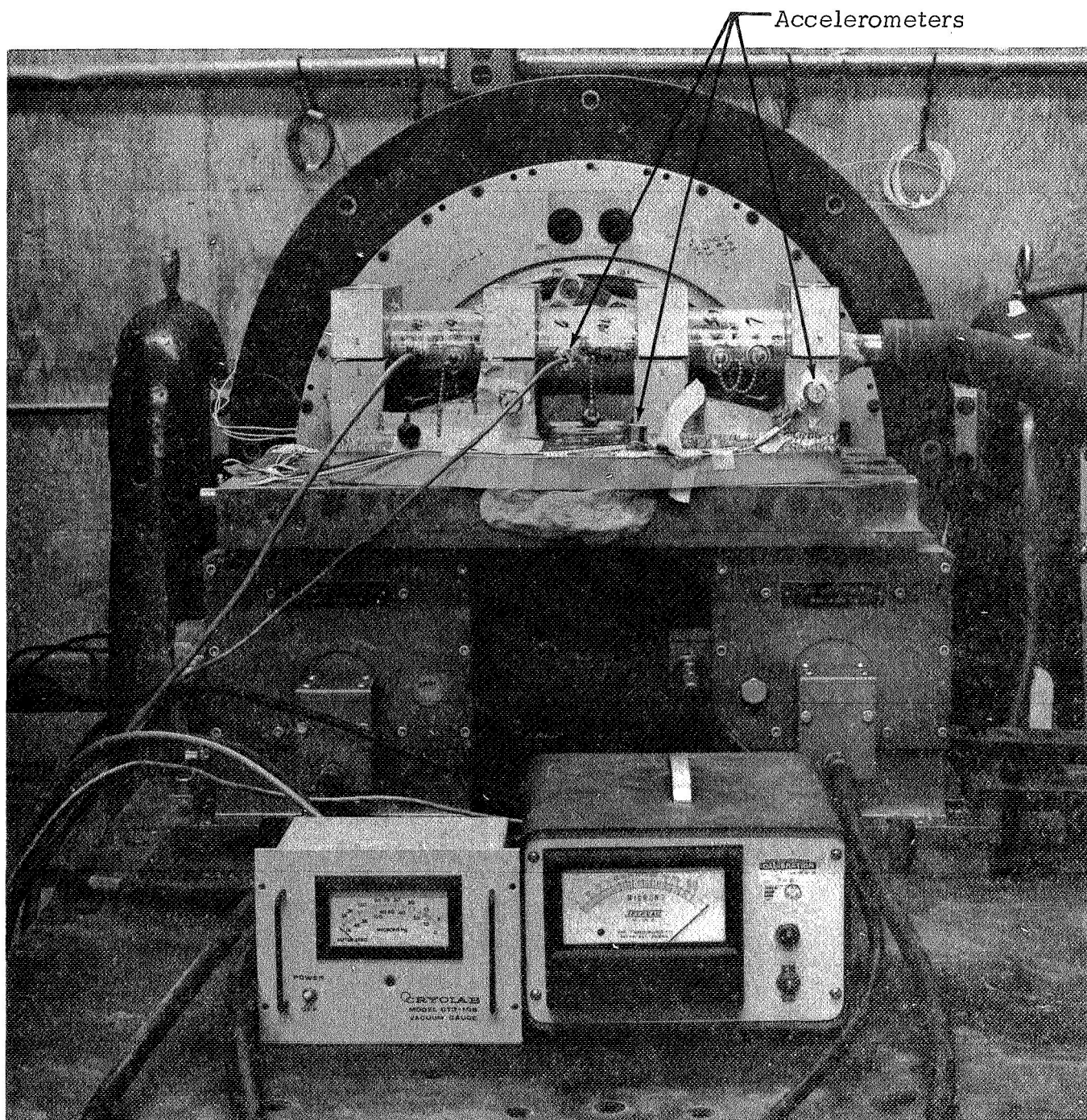


Figure 30.
Vibration Test Of Vacuum Probes In The Y-Axis

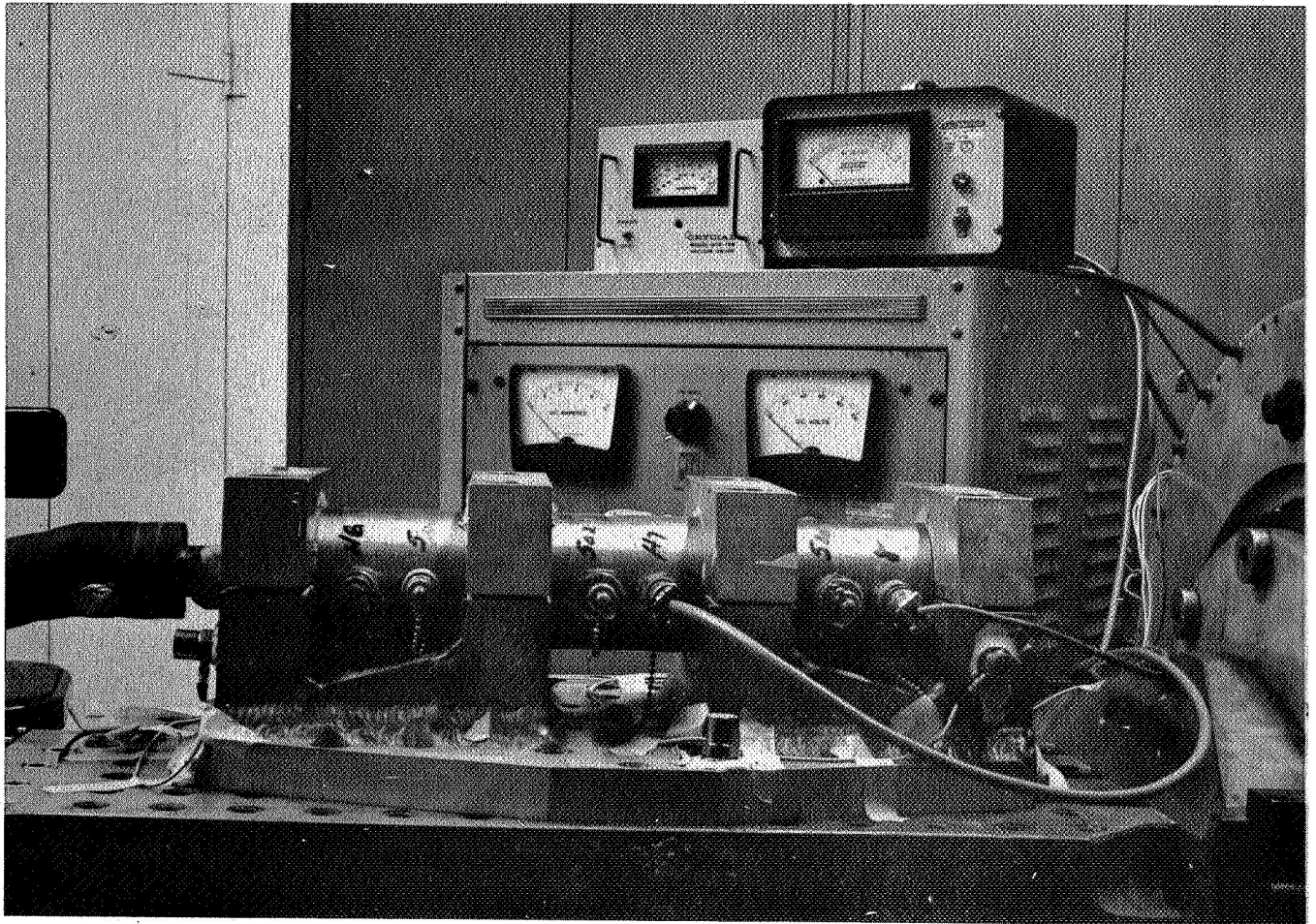


Figure 31.
Vibration Test Setup for the Vacuum Gauge Probes in the Z-Axis

D. Test Results

The vibration fixture was determined to have a small resonant at 1700 Hz. This resonance was compensated for by placing the control accelerometer on the test manifold and damping the manifold by placing Apcock (putty) between the manifold and vibration fixture. No detectable resonances could be found for any of the test specimens during the resonant search part of the vibration test.

The vacuum probes were first tested in the X-Axis. During the resonant sweep all of the Hastings-Raydist vacuum probes failed electrically. The photograph on page 88 shows two of the Hastings-Raydist probes dissected to determine the cause of failure. In one of the probes, the sensing wires were torn completely away from their mounting post, while the other had several wires broken at the mounting post. The cause of failure was attributed to the relatively large junction beads resonating and breaking the thermocouple wires. No leakage was noted in any of the units during vibration in the X-axis.

Vibration in the Z-axis caused no damage to the remaining probes. However, due to difficulties with the power amplifier of the vibration console only 15 g's were obtainable. Since the X and Z axes were nearly similar, the test was completed at this level. No leakage was noted in the Z-axis.

During vibration in the Y-axis (see photograph on page 85) the A element of Cryolab vacuum probe Serial No. H6 failed electrically. Since the B element was still active, a failure analysis was not performed. No leakage was detectable in the Y-axis.

During the functional test, one out of specification reading was obtained for the Fredericks vacuum probe, Serial No. 3 at the 20 micron vacuum level. Cryolab specimen H6, element A had an atmospheric indication at all pressure levels. Vibration seemed to improve the Cryolab reading at the 1000 micron level with all active elements reading within specification.

TYPICAL FAILURE

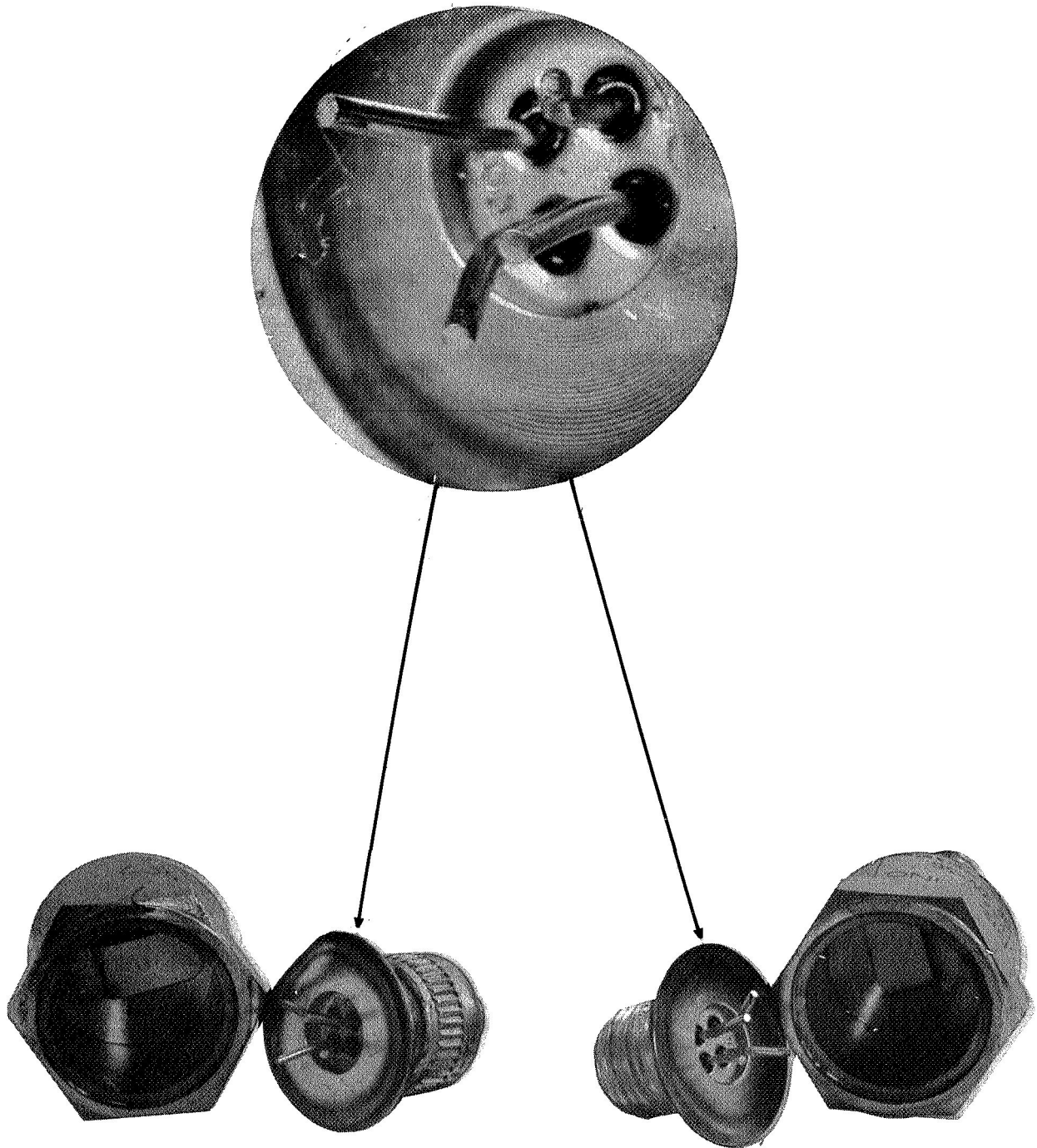


Figure 32.
Failure Analysis After Vibration Of The Hasting Vacuum Gauge
Showing The Sensing Wires Broken Away From The Mounting Posts

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician *mcKnight*

Date: 10/29/69

Test AFTER VIBRATION

Standard		Microns													
		< 1		20		50		100		200		500		1000	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cryolab															
/N GT3-008-5T3															
Serial Number	H1	4	1	20	17	50	49	95	95	190	200	525	550	950	900
LEAK RATE ALL	H2	3	1	20	17	53	48	105	95	210	195	600	575	1000	950
<1 X 10 ⁻¹⁰	H3	1	1	18	18	49	48	100	96	200	200	600	600	975	950
	H4	<1	<1	17	18	44	49	90	100	190	200	550	600	900	950
	H5	1	9	17	25	46	55	92	105	190	220	525	600	950	1000
	H6	ATM	1	ATM	16	ATM	48	ATM	93	ATM	200	ATM	575	ATM	1000
	H7	1	1	17	17	46	46	92	95	190	195	525	525	900	900
	H8	<1	<1	18	17	49	46	100	95	200	195	600	550	1000	900
Fredericks															
P/N 2100-32															
Serial Number	1	6		20		51		95		200		500		1000	
	2	4		21		50		98		200		500		1000	
LEAK RATE ALL	3	< 1		14		48		95		210		600		1000	
<1 X 10 ⁻¹⁰	4	5		21		51		100		205		550		1000	
	5	< 1		19		47		98		200		500		1000	
	6	2		18		46		97		195		500		1000	
	7	1		19		46		98		190		500		1000	
	8	1		18		45		95		190		500		1000	
Castings															
/N DV-36															
Serial Number	486														
	495														
	502														
	507														
	509														
	511														
	515														
	520														

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration Date of Test 11/4/69
 Part Name Vacuum Probe Part Number Cryolab GT3-008-5T3
 Test Procedure 8-440090 Part Serial Number H1, H2, H3, H4, H5, H6, H7, H8.
 Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0-10 g's RMS
0-100 g's RMS

Bolt Torque Values _____

Sine cond	Search Time	25° /Min.
	Sweep Time	16° /Min.
Search	20 to 75 cps @ 0.01 in. D.A.	
	75 to 3000 cps @ 3 G's peak	
Sweep	10 to 75 cps @ 0.10 in. D. A.	
	75 to 2000 cps @ 30 G's peak	
Z Axis Sweep	10 to 75 cps @ 0.05 in. D. A.	
	75 to 1500 cps @ 15 G's peak	

Accelerometer Placement
 Sketch _____

See Photograph

Random Cond. Random Noise Duration _____

Resonant Search

	_____ to _____ cps @ _____ in. 2/cps	Sweep Time	A X I S		
	_____ to _____ cps @ _____ G 2/cps	Resonant Frequency	X	Y	Z
	_____ to _____ cps @ _____ db octave				
	_____ to _____ cps @ _____ G 2/cps				
	_____ to _____ cps @ _____ db octave				
Axis	Remarks	Dwell time or Sweep time	Operator		
X	No Failure	15 Min. 20 Min.	9/29/69		
Y	No Failure	15 Min. 20 Min.	10/28/69		
Z	No Failure	15 Min. 20 Min.	10/28/69		

Test Technician *[Signature]* Inspection _____

Test Engineer _____

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration Date of Test 11/4/69

Part Name Vacuum Probe Part Number Fredericks 2100-32

Test Procedure 8-440090 Part Serial Number 1, 2, 3, 4, 5, 6, 7, 8

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0-10 g's RMS
0-100 g's RMS

Accelerometer Placement
Sketch

Bolt Torque Values

Sine cond Search Time 25° /Min.
Sweep Time 16° /Min.

Search 20 to 75cps @ 0.01in. D.A.

75 to 3000cps @ 3 G's peak

Sweep 10 to 75cps @ 0.10in. D. A.

75 to 2000cps @ 30 G's peak

Z Axis 10 to 75cps @ 0.05in. D. A.

Sweep 75 to 1500cps @ 15 G's peak

See Photograph

Random Cond. Random Noise Duration

Resonant Search

 to cps @ in. 2/cps
 to cps @ G 2/cps
 to cps @ db octave
 to cps @ G 2/cps
 to cps @ db octave

Sweep Time

Resonant Frequency

A X I S

X

Y

Z

Axis

Remarks

Dwell time or Sweep time

Operator

X

No Failure

15 Min.

20 Min.

9/26/69

Y

No Failure

15 Min.

20 Min.

10/28/69

Z

No Failure

15 Min.

20 Min.

10/27/69

Test Technician *ma Smith* Inspection

Test Engineer

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration Date of Test 11/4/69
 Part Name Vacuum Probe Part Number Hasting DV 36
 Test Procedure 8-440090 Part Serial Number 486, 495, 502, 507, 509, 511, 515, 520.
 Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0-10 g's RMS
0-100 g's RMS

Bolt Torque Values _____

Sine cond	Search Time	25° /Min.
	Sweep Time	16° / Min.
Search	20 to 75 cps @	0.01 in. D.A.
	75 to 3000 cps @	3 G's peak
Sweep	10 to 75 cps @	0.10 in. D. A.
	75 to 2000 cps @	30 G's peak
	to cps @	in. D. A.
	to cps @	G's peak

Accelerometer Placement
 Sketch _____

See Photograph

Random Cond. Random Noise Duration _____

Resonant Search

	_____ to _____ cps @ _____ in. 2/cps	Sweep Time			
	_____ to _____ cps @ _____ G 2/cps	Resonant Frequency	A X I S		
	_____ to _____ cps @ _____ db octave		X	Y	Z
	_____ to _____ cps @ _____ G 2/cps				
	_____ to _____ cps @ _____ db octave				
	_____ to _____ cps @ _____ db octave				
Axis	Remarks	Dwell time or Sweep time	Operator		
X	Failed Elect. During Sweep - No Leakage	15 Min. 20 Min.	9/26/69		

Test Technician *MacBride* Inspection _____

Test Engineer _____

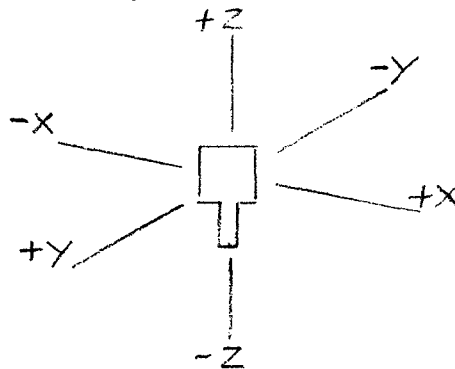
5.2.2.4.9 Shock Test

A. Test Requirements

The shock test was to be performed to evaluate the vacuum probes for resistance to shock during normal service, installation, handling and shipment.

The test was to be conducted in accordance with Section 10 of KSC-STD-164D. The test specimens were to be installed on the test fixture and in accordance with Paragraph 4.4.1 of KSC-STD-164D. The tests were to be conducted in accordance with the following parameters:

- (1) Pulse shape - one-half sine wave
- (2) Duration - 2 ms \pm 0.6 ms or \pm 15%, whichever is greater.
- (3) Amplitude - 30 g \pm 15%
- (4) Definition of axes and direction of shock along each axes. Axes are defined below. Direction of shock was to be in both directions in each of the three mutually perpendicular axes.



- (5) Sequence in which axes were to be tested:
 - a. Axis X + to -
 - b. Axis X - to +
 - c. Axis Y + to -
 - d. Axis Y - to +
 - e. Axis Z + to -
 - f. Axis Z - to +

B. Test Procedure

The vibration fixture was designed to be used as the shock test fixture. The test fixture with a dummy load was installed on the impact tester and the machine parameters were adjusted until a one-half sine pulse of 2 ms duration at 30 g's was obtained.

The test manifold with the test specimens was then installed and the prescribed shock tests were conducted. The photographs on pages 95 and 96 show the test setup and page 97 is a photograph of a typical shock pulse.

C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Shock Machine	Monterey Research Laboratory	2424	5	500 lbs/ 100 g's	---	Prior to Use
Accelerometer	Endevco	224-2M4	6897	5-7000Hz	±5%	Prior to Use
Charge Amplifier	Endevco	2708	LA23	0.03Hz - 100KHz - 0-50, 000 g's	±1.5%	Prior to Use
Oscilloscope	Dumont	401B	1020	DC500KC	---	Prior to Use
Camera	Fairchild	453	1114	---	---	---
McLeod Vacuum Gauge	Todd Scientific Co.			0-25MM	---	Prior to Use
Mass Spectrometer Leak Detector	National Research Corporation	925	0925J009	5.4×10^{-6} 1×10^{-10}	±10%	Prior to Use
Vacuum Pump	National Research Corporation	3305	2266-8820	1×10^{-6}	---	---
Vacuum Gauge	Hastings	VT-6B	9839	0-ATM	---	Every 3 mos
Vacuum Gauge	Cryolab	GT3-108	---	0-1000 microns	---	---
Vacuum Gauge	Televac	2A	5117	0-1000 microns	---	Every 3 mos

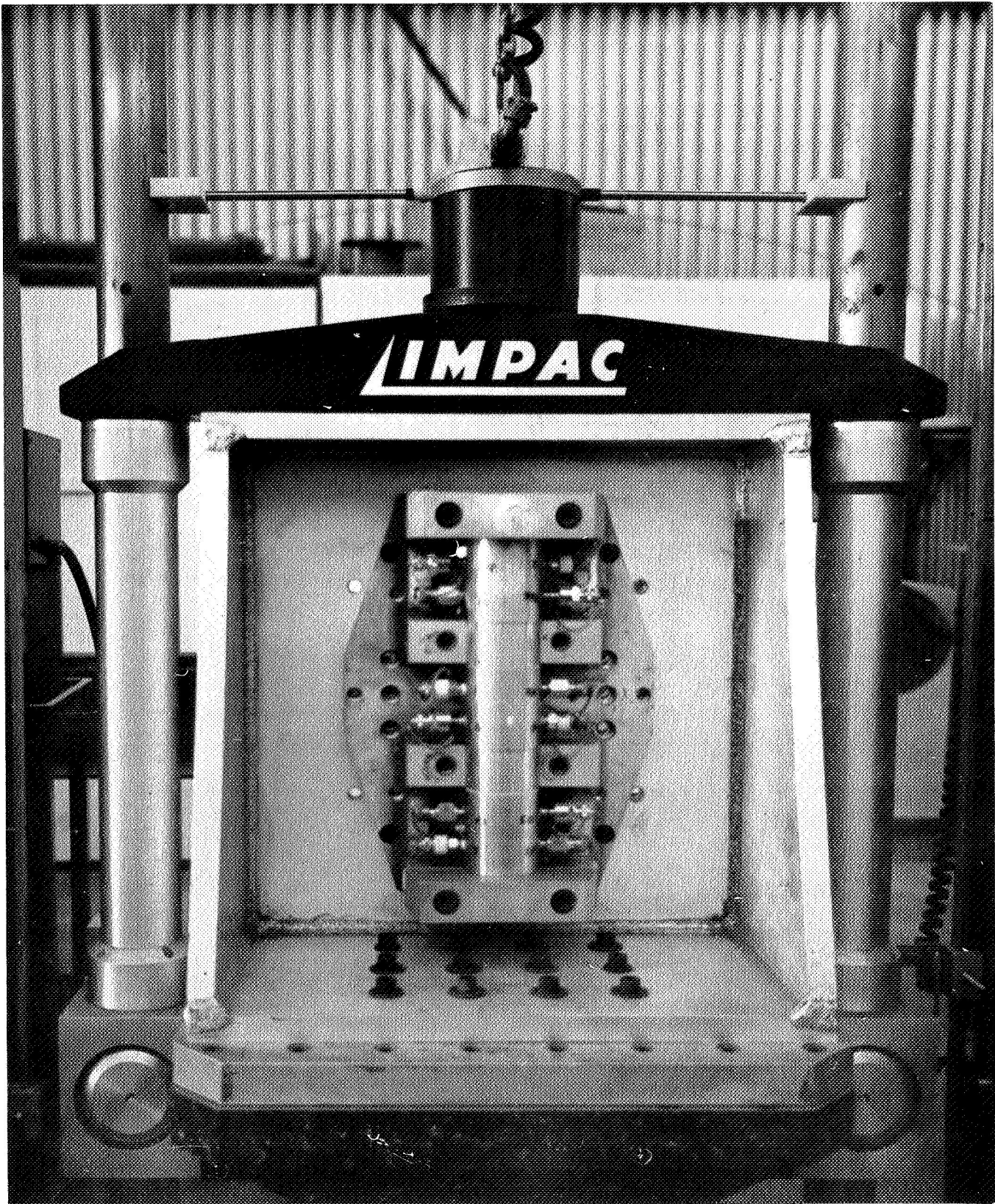


Figure 33.
Shock Test Setup For Vacuum Gage Tubes In X-X Axes



Figure 34.
Shock Test Setup For Vacuum Gage Tubes In Z-Z Axes

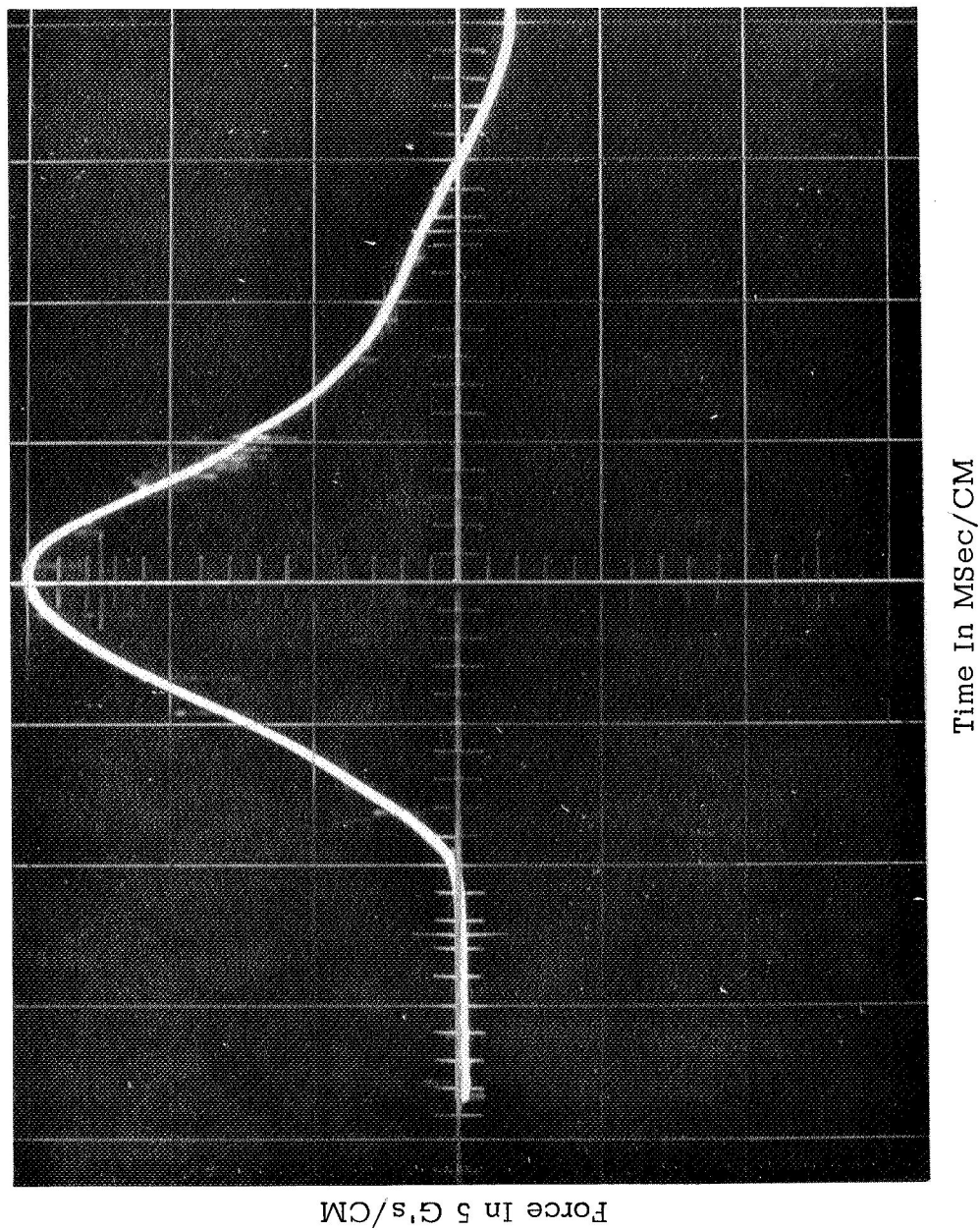


Figure 35.
Typical Shock Pulse Waveform During Shock Test For Burst Discs,
Seal-Off Valves, And Vacuum Probes

D. Test Results

Since the failure of the Hastings-Raydist vacuum probes during the vibration test, only the Cryolab and Fredericks probes were observed during the shock test. All remaining active units successfully passed the shock test. All vacuum probes were within specification during the accuracy test after shock except the Cryolab probe Serial No. H5, element B at the 1 micron level and probe Serial No. H6, element A which still remained at atmospheric.

Leakage was less than 1×10^{-6} std cc/sec of helium gas.

VACUUM GAGE TUBE
ACCEPTANCE TEST DATA SHEET
FUNCTIONAL TEST

Test Technician McKnight

Date: 11/9/69

Test AFTER SHOCK

Standard		Microns													
		<1		20		50		100		200		500		1000	
Cryolab		A	B	A	B	A	B	A	B	A	B	A	B	A	B
P/N GT3-008-5T3															
Serial Number	H1	1	4	18	24	49	50	96	100	195	195	550	590	900	900
	H2	2.5	<1	22	18	52	46	109	96	210	195	600	600	950	900
LEAK RATE ALL	H3	3	3	19	18	49	47	100	100	200	200	500	500	900	950
<1 X 10 ⁻¹⁰	H4	1	2	17	18	46	49	95	102	185	200	490	500	900	1000
	H5	<1	9	18	26	46	56	96	110	195	220	550	510	900	1000
	H6	ATM	<1	ATM	18	ATM	47	ATM	99	ATM	200	ATM	700	ATM	950
	H7	3	3	17	17	47	47	95	94	195	195	520	550	900	950
	H8	3	2	19	17	50	46	105	95	200	195	500	510	950	900
Fredericks															
P/N 2100-32															
Serial Number	1	4		23		51		100		200		500		1000	
	2	3		22		49		100		198		600		1000	
LEAK RATE ALL	3	<1		16		43		99		200		600		1000	
<1 X 10 ⁻¹⁰	4	5		24		53		105		200		700		1000	
	5	5		20		49		99		198		500		1000	
	6	4		20		48		98		190		440		1000	
	7	3		21		48		98		198		495		1000	
	8	5		20		49		95		190		480		1000	
Hastings															
P/N DV-36															
Serial Number	486														
	495														
LEAK RATE ALL	502														
<1 X 10 ⁻¹⁰	507														
	509														
	511														
	515														
	520														

5.2.2.4.10 Accelerated Life Test (Vibration)

A. Test Requirements

The accelerated life test was to be performed to determine the highest critical service envelope in which the test item can be used.

The test item was to be installed in the test fixture. The test item was to be subjected to vibration tests in accordance with KSC-STD-164D, Paragraph 9.2 and Procedure 11a, Paragraphs 9.3.1 and 9.3.5, except that the test levels were to be as specified in this document. The sequence of testing, excepting failures which may occur before the conclusion of the test program, was:

- (1) Resonant frequency search,
- (2) Sinusoidal dwell, and
- (3) Random.

1. Resonant Frequency Search

The test item was to be installed in accordance with Paragraph 4.4.1 of KSC-STD-164D. The fixture/test item assembly was to be exposed to sinusoidal vibration at an acceleration of 3 g's. The frequency range of 5 to 300 cps was to be traversed logarithmically in directions of both increasing and decreasing for a period not to exceed 15 minutes. The test item was to be functionally tested at the conclusion of the test

2. Sinusoidal Dwell

The test item was to be exposed to sinusoidal vibration beginning at the most severe resonant frequency in the most critical axis determined by the resonant frequency search test. The input level was to be increased until the test item shows signs of structural deterioration or failure. The test duration was not to exceed 1 minute. In no event was the input level to exceed the maximum level specified by the test engineer.

If no structural deterioration occurred when this level was reached, the test was to proceed to the most severe resonant frequency in the next most critical axis. After all three axes had been tested, additional testing was to be performed on the basis of the next most severe resonant frequency without regard to axis.

3. Random

The test item was to be subjected to white noise random vibration over a frequency range confined by the lowest and highest resonant or critical frequencies determined by the resonant frequency search test. The axis containing the most severe resonant frequency was to be tested first. The initial test level was to be determined by using the formula per Paragraph 4.3.5.2 of KSC-STD-164D.

B. Test Procedure

Due to limited schedule time for completion of the test program, a modified accelerated life test was conducted. The specimens were mounted in the vibration fixture and the fixture was installed on the vibration excitor in the X-axis.

Five sine sweeps were made increasing in increments of 5 g's from 35 g's to 55 g's. The specimens were monitored for leakage and checked electrically after each sweep.

Testing was completed in the X-axis only. Due to numerous failures no final functional test was conducted.

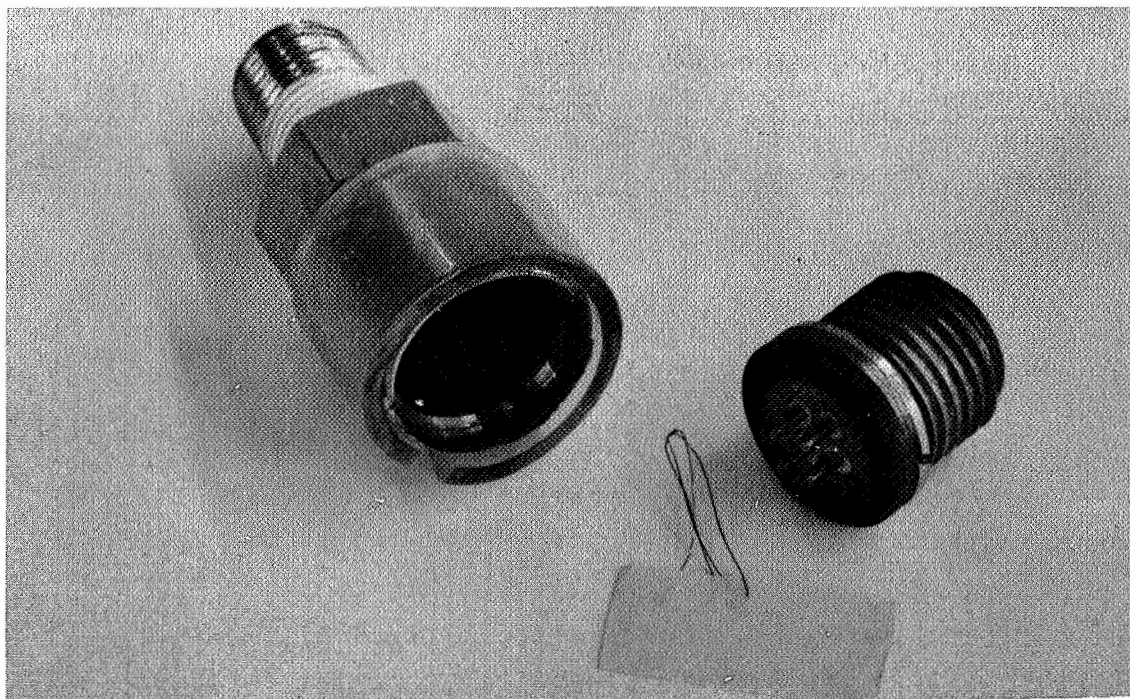
C. Test Equipment

Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Automatic Vibration Excitor Control	Bruel & Kjoer	1018	80029	5 - 10KHz	±1%	Daily Prior to Use
Power Amplifier	Ling	CP10/16AVC	61	5-3000Hz	---	---
Shaker	Ling	B-300	68	5-3000Hz	---	---
Accelerometer	Endevco	2242C	FA44	5-6000Hz	±5%	Daily Prior to Use
Accelerometer	Endevco	2242C	FA75	5-6000Hz	±5%	Daily Prior to Use
Accelerometer	Endevco	2242C	FA79	5-6000Hz	±5%	Daily Prior to Use

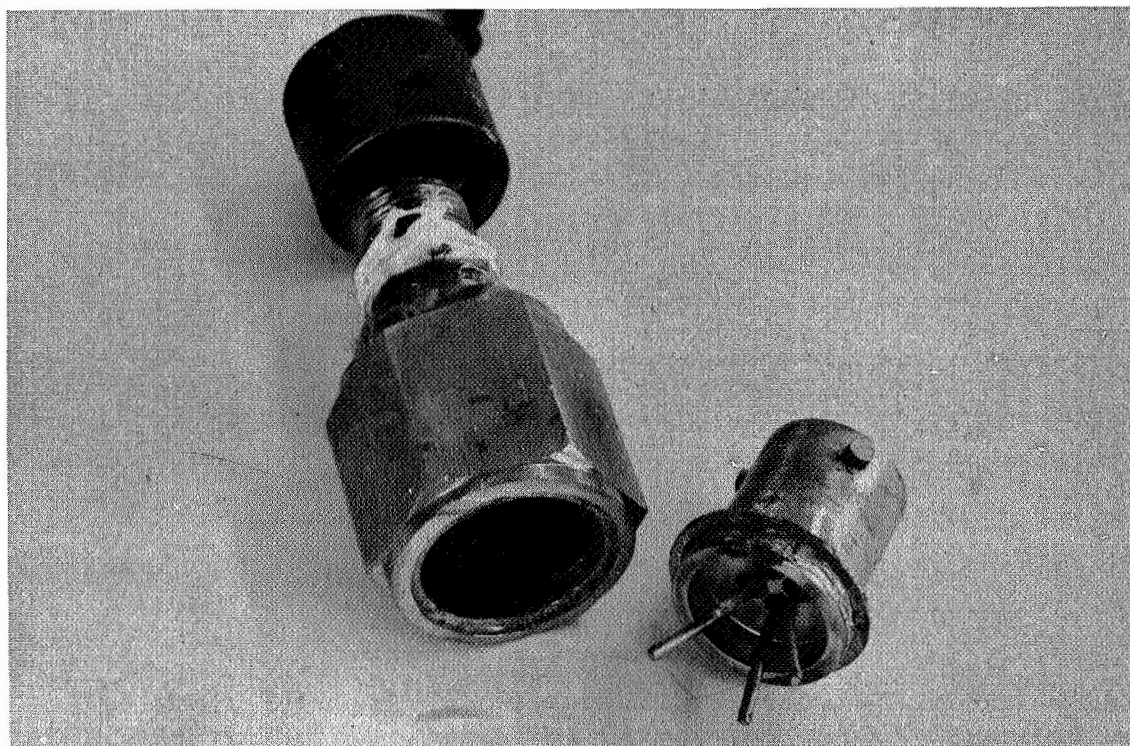
Type	Manufacturer	Model	Serial No.	Range	Accuracy	Calibration
Accelerometer	Endevco	2242C	HB21	5-6000Hz	±5%	Daily Prior to Use
Accelerometer	Unholtz-Dickie	603R	165	10-5000Hz	±2%	Daily Prior to Use
Dynamic Analyzer	Spectral Dynamics	SD101A	330	2-25KHz	±0.25db	Daily Prior to Use
Vacuum Voltmeter	Hewlett-Packard	400D	310-50190	10-4MC	±2%	Every 3 mos
Electronic Counter	Hewlett-Packard	521C	2427	1-120KHz	±1 count or 0.01%	Every 6 mos
Oscilloscope	Dumont	401B	1020	0-500KC	---	Daily Prior to Use

D. Test Results

Of the eight Fredericks vacuum probes tested, one failed at 40 g's and two failed at 55 g's. Only one failure was encountered with the Cryolab vacuum probes at 55 g's. Pages 104 through 109 are the data sheets for the accelerated life test. Page 103 shows the typical failure encountered with the sensing wires breaking at the mounting post.



Fredericks Vacuum Probe — Note Sensing Elements Broken Completely From Mounting Posts



Cryolab Vacuum Probe — Typical Failure Of Vacuum Probes After The Accelerated Life Test

Figure 36.

DESIGN VERIFICATION TEST
TEST DATA SHEET

Type of Test Vibration Accelerated Life Date of Test 11/13/69

Part Name Vacuum Probe Part Number Fredericks 2100-32

Test Procedure 8-480090 Part Serial Number 2, 4, 7.

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0 - 100 g's RMS

Accelerometer Placement
Sketch

Bolt Torque Values _____

Sine cond	Sweep Time <u>16° /Min.</u>
Sweep No. 1	<u>10 to 75 cps @ 0.12 in. D.A.</u> <u>75 to 1500 cps @ 35 G's peak</u>
No. 2	<u>10 to 75 cps @ 0.14 in. D. A.</u> <u>75 to 1500 cps @ 40 G's peak</u>
No. 3	<u>10 to 75 cps @ 0.155 in. D. A.</u> <u>75 to 1500 cps @ 45 G's peak</u>

Sweep
No. 4 10 to 75 cps @ 0.17 in. D.A.
75 to 1500 cps @ 50 G's Peak
No. 5 10 to 75 cps @ 0.19 in. D.A.
75 to 1500 cps @ 55 G's Peak

Random Cond. Random Noise Duration _____

Resonant Search

	to _____ cps @ _____ in. 2/cps	Sweep Time	A X I S		
	to _____ cps @ _____ G 2/cps	Resonant Frequency	X	Y	Z
	to _____ cps @ _____ db octave				
	to _____ cps @ _____ G 2/cps				
	to _____ cps @ _____ db octave				
Axis	Remarks	Dwell time or Sweep time	Operator		
X	No Failure	20 Min.	11/11/69		

Test Technician ma Bright Inspection _____

Test Engineer _____

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration -Accelerated Life Date of Test 11/13/69

Part Name Vacuum Probe Part Number Fredericks 2100-32

Test Procedure 8-480090 Part Serial Number 3

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0 - 100 g's RMS

Bolt Torque Values _____

Accelerometer Placement
Sketch _____

Sine cond	Sweep Time <u>16° /Min.</u>
Sweep No. 1	<u>10 to 75</u> cps @ <u>0.12</u> in. D.A. <u>75 to 1500</u> cps @ <u>35</u> G's peak
No. 2	<u>10 to 75</u> cps @ <u>0.14</u> in. D. A. <u>75 to 1500</u> cps @ <u>40</u> G's peak
No. 3	<u>10 to 75</u> cps @ <u>0.155</u> in. D. A. <u>75 to 1500</u> cps @ <u>45</u> G's peak

Sweep No. 4	<u>10 to 75</u> cps @ <u>0.17</u> in.D.A. <u>75 to 1500</u> cps @ <u>50</u> g's Peak
No. 5	<u>10 to 75</u> cps @ <u>0.19</u> in. D.A. <u>75 to 1500</u> cps @ <u>55</u> g's Peak

Random Cond. Random Noise Duration _____

Resonant Search

	<u> </u> to <u> </u> cps @ <u> </u> in. 2/cps	Sweep Time	A X I S		
	<u> </u> to <u> </u> cps @ <u> </u> G 2/cps	Resonant Frequency	X	Y	Z
	<u> </u> to <u> </u> cps @ <u> </u> db octave				
	<u> </u> to <u> </u> cps @ <u> </u> G 2/cps				
	<u> </u> to <u> </u> cps @ <u> </u> db octave				

Axis	Remarks	Dwell time or Sweep time	Operator
X	Failed Elect at 35 g's	20 Min.	11/11/69

Test Technician *MacBride* Inspection _____

Test Engineer _____

DESIGN VERIFICATION TEST
TEST DATA SHEET

Type of Test Vibration-Accelerated Life Date of Test 11/13/69

Part Name Vacuum Probe Part Number Fredericks 2100-32

Test Procedure 8-480090 Part Serial Number 1, 8.

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0 - 100 g's RMS

Accelerometer Placement
Sketch

Bolt Torque Values

Sine cond	Sweep Time <u>16° /Min.</u>
Sweep No. 1	<u>10 to 75 cps @ 0.12 in. D.A.</u> <u>75 to 1500 cps @ 35 G's peak</u>
No. 2	<u>10 to 75 cps @ 0.14 in. D. A.</u> <u>75 to 1500 cps @ 40 G's peak</u>
No. 3	<u>10 to 75 cps @ 0.155 in. D. A.</u> <u>75 to 1500 cps @ 45 G's peak</u>

Sweep No. 4 10 to 75 cps @ 0.17 in. D.A.
75 to 1500 cps @ 50 g's Peak
No. 5 10 to 75 cps @ 0.19 in. D. A.
75 to 1500 cps @ 55 g's Peak

Random Cond. Random Noise Duration

Resonant Search

	<u>to cps @ in. 2/cps</u> <u>to cps @ G 2/cps</u> <u>to cps @ db octave</u> <u>to cps @ G 2/cps</u> <u>to cps @ db octave</u>	Sweep Time	A X I S		
		Resonant Frequency	X	Y	Z
Axis	Remarks	Dwell time or Sweep time	Operator		
X	Failed Elect. at 40 g's	20 Min.	11/11/69		

Test Technician *ma Bright* Inspection _____

Test Engineer _____

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration - Accelerated Life Date of Test 11/14/69

Part Name Vacuum Probe Part Number Fredericks 2100-32

Test Procedure 8-480090 Part Serial Number 5, 6.

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0-100 g's RMS

Accelerometer Placement
Sketch

Bolt Torque Values

Sine cond	Sweep Time <u>16° /Min.</u>
Sweep No. 1	<u>10 to 75 cps @ 0.12 in. D.A.</u> <u>75 to 1500 cps @ 35 G's peak</u>
No. 2	<u>10 to 75 cps @ 0.14 in. D. A.</u> <u>75 to 1500 cps @ 40 G's peak</u>
No. 3	<u>10 to 75 cps @ 0.155 in. D. A.</u> <u>75 to 1500 cps @ 45 G's peak</u>

Sweep No. 4 10 to 75 cps @ 0.17 in. D.A.
75 to 1500 cps @ 50 g's Peak
No. 5 10 to 75 cps @ 0.19 in D. A.
75 to 1500 cps @ 55 g's Peak

Random Cond. Random Noise Duration

Resonant Search

	<u> </u> to <u> </u> cps @ <u> </u> in. 2/cps	Sweep Time	A X I S		
	<u> </u> to <u> </u> cps @ <u> </u> G 2/cps	Resonant Frequency	X	Y	Z
	<u> </u> to <u> </u> cps @ <u> </u> db octave				
	<u> </u> to <u> </u> cps @ <u> </u> G 2/cps				
	<u> </u> to <u> </u> cps @ <u> </u> db octave				
Axis	Remarks	Dwell time or Sweep time	Operator		
X	Failed Elect. at 55 g's	20 Min.	11/12/69		

Test Technician *Smith* Inspection

Test Engineer

DESIGN VERIFICATION TEST

TEST DATA SHEET

Type of Test Vibration - Accelerated Life Date of Test 11/13/69

Part Name Vacuum Probe Part Number Cryolab GT3-008-5T3

Test Procedure 8-480090 Part Serial Number H5

Type of Recorder Sanborn 350 No. of Channels 6

Recording Calibration 0-100 g's RMS

Bolt Torque Values _____

Accelerometer Placement
Sketch _____

Sine
cond
Sweep
No.1 Sweep Time 16°/min.
10 to 75cps @ 0.12 in. D.A.
75 to 1500cps @ 35 G's peak
No.2 10 to 75cps @ 0.14 in. D. A.
75 to 1500cps @ 40 G's peak
No.3 10 to 75cps @ 0.155 in. D. A.
75 to 1500cps @ 45 G's peak

Sweep
No. 4 10 to 75 cps 0.17 in. D.A.
75 to 1500 cps 50 G's Peak
No. 5 10 to 75 cps 0.19 in. D.A.
75 to 1500 cps 50 G's Peak

Random
Cond. Random Noise Duration _____

Resonant Search

_____ to _____ cps @ _____ in. 2/cps
_____ to _____ cps @ _____ G 2/cps
_____ to _____ cps @ _____ db octave
_____ to _____ cps @ _____ G 2/cps
_____ to _____ cps @ _____ db octave

Sweep Time	A X I S		
Resonant Frequency	X	Y	Z

Axis	Remarks	Dwell time or Sweep time	Operator
X	Side "B" Failed Elect. at 50 G's	20 min.	11/11/69

Test Technician _____ Inspection _____

Test Engineer _____

Conclusions

Review of the test data for the accuracy test after each environmental test reveals minor variations in apparent micron levels for individual vacuum probes over the test period and changes in output of several of the probes indicating some type of contamination of the sensing element. Preparation of the test manifold included some cleaning followed by cleaning for liquid oxygen service to preclude any introduction of contamination. Between and during tests the inlet port to the manifolds were covered, but the continual release to atmosphere and re-evacuation may have contributed to the change in output of a particular vacuum probe. This discussion is limited to Cryolab test specimens, Serial No. H5, Element B and Serial No. H1, Element A, and Hastings-Raydist test specimen No. 515. In reviewing the data it should be remembered that all of the test specimens were evacuated and evaluated for accuracy at the same time, and that the 24 specimens had a random distribution on the two test manifolds.

The McLeod Gauge used for determining vacuum level was not calibrated by a standard traceable to the NBS, but was used solely as a reference gauge. Test results, particularly those of the Fredericks vacuum probe shows close correspondence of readings.

Numerous out-of-specification readings were recorded during the functional accuracy test with the Fredericks vacuum probes having the least over the total program.

Two of the Cryolab vacuum probes developed leaks through the silver solder seal between the electrical connector and the body of the probe. One failure occurred after salt fog and the other after the high temperature test.

Both of these failures would be cause for loss of vacuum in a line and eventual cause for rejection. These failures were considered to be a Quality Control problem since silver soldering is a proven method for vacuum seals and is used frequently in the industry. One element of one of the Cryolab probes failed vibration at 30 g's; however, since this is a dual element probe, the unit would still function as required. During the accelerated life test (vibration), only one failure of one element of the Cryolab vacuum probes occurred at 55 g's sine sweep.

The Fredericks vacuum probes passed all phases of the testing including vibration at 30 g's without any failures due to leakage or electrical failures. A few out of specification readings were noted particularly after the high temperature test. During the

accelerated life test (vibration) the first Fredericks vacuum probe failed at 35 g's with a total of five failures out of eight from 35 g's to 50 g's sine sweep. The Fredericks vacuum probes used as test specimens installed in the lines at Cape Kennedy would not have been cause for any rejection over the test period. All of the Hastings-Raydist vacuum probes failed the vibration test at 30 g's sine sweep.

It was noted during testing that the Cryolab and Hastings-Raydist probes were more susceptible to changes in readings due to apparent contamination, as compared to the Fredericks vacuum probe. The only physical difference in construction is that the Fredericks probes sensing elements were constructed of heavier gauge wire giving a smaller surface to volume ratio thereby being less sensitive to cooling effects of contamination.

During the total test program no probe leakage developed at the threaded mounting. This includes all vacuum probes with only the original installation connection. The method of installation was to apply Teflon tape to the threads followed by a thin coat of silvac, a vacuum sealant and then installing the vacuum probe in the manifold.

In summary, the Fredericks vacuum probe had the least deviation during the functional tests and with no failures encountered until accelerated life. Also, the Fredericks vacuum probes seem to be less susceptible to contamination. The effectiveness of the dual element found in Cryolab vacuum probes is indicated in the one failure of one element during vibration at 30 g's, with the remaining element still active and the unit functioning. The leakage of the Cryolab probes through the silver solder seal indicated some Quality Control problems. The Hastings-Raydist vacuum probes were susceptible to vibration with all units failing the 30 g's sine sweep. The Fredericks vacuum probe should be retained as the **primary source with the Cryolab probe developed as a second source.**

An expanded upper scale on the meters would be effective since difficulty was encountered in making accurate readings in general above 500 microns. Since many vacuum jacketed cryogenic propellant lines will effectively cryopump from 4000 microns down, an expanded scale becomes attractive.

5.3

PROCUREMENT SPECIFICATION

A procurement specification entitled "Vacuum Probes — Vacuum Jacketed Cryogenic Transfer and Storage Systems" with NASA Specification No. 79K00112 was created from information obtained during the Phase I portion of the study and the results of vacuum probe testing. It is expected that future vacuum probe procurement will be made with this specification. The specification was submitted to NASA under contract no. NAS10-6098.

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